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MDCCCXXXIX.

Adjudication of the Medals of the Royal Society for the year 1839 by the President and Council.

The Copley Medal to Robert Brown, Esq., D.C.L., F.R.S., for his discoveries, during a series of years, on the subject of Vegetable Impregnation.

The Royal Medal, in the department of Astronomy, to James Ivory, Esq., K.H., F.R.S., for his paper entitled "On the theory of the Astronomical Refractions," published in the Philosophical Transactions for 1838.

The Royal Medal, in the department of Physiology, including the Natural History of Organized Beings, to Martin Barry, M.D., for his papers entitled "Researches in Embryology," published in the Philosophical Transactions for 1838 and 1839.

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APPENDIX.

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Meteorological Journal kept at the Apartments of the Royal Society, by order of the President and Council.

PHILOSOPHICAL TRANSACTIONS.

XIV. The Bakerian Lecture.—*Inquiries concerning the Elementary Laws of Electricity.—Third Series.* By W. Snow Harris, *Esq. F.R.S.*

Received May 4,—Read June 20, 1839.

1. THERE is no department of science in which the perfection of quantitative measurement, and a clear perception of what we really measure, is more called for than in that of electricity. If we except the valuable researches of Professor Robison and of Coulombe, and the more recent investigations of Dr. Faraday, we can scarcely be said to possess, in common electricity at least, any connected series of experiments carrying with them a rigid numerical value. In the various inquiries into the elementary laws of electricity, which I have had the honour of submitting to the consideration of the Royal Society, it has been my endeavour to perfect our methods of electrical measurement, whether relating to the quantity of electricity, intensity, inductive power, or other element requiring an exact numerical value, and, by operating with large statical forces both attractive and repulsive, to avoid many sources of error inseparable from the employment of very small quantities of electricity, such as those affecting the delicate balance used by Coulombe.

The instruments resorted to in these further inquiries have been employed with this view; they have been already described*; I have only occasion to briefly mention some recent improvements in the hydrostatic electrometer mentioned in my first paper*, and represented in Plate III. fig. 1.

2. In the instrument here shown, the column M, carrying the graduated arc, and wheelwork W, consists of two cylindrical brass tubes *t*, *t*, about an inch in diameter and fourteen inches high. That on which the wheelwork is placed moves freely within the other, so as to be readily elevated or depressed by means of a rack fixed in it, and a pinion attached to the upper part of the outer tube at M. The object of this motion is to enable the experimenter to vary the distance between the attracting or repelling discs *m*, *f* without disturbing the lower disc *f*, or otherwise to adjust the same

* Philosophical Transactions for 1834.

distance by changing the position of both the discs, manipulations which greatly simplify many intricate cases of experiment.

3. In order to estimate the distances when the position of the disc *m* is varied, a graduated sliding piece *t*, about three inches long, is placed upon the inner tube, free of the rack-work, and being moveable upon it with friction, may be set with any required altitude of the whole column M to zero of its scale. In this way all subsequent changes of distance produced by elevating or depressing the interior tube *t* are easily known.

Changes of distance attendant on the motion of the lower disc *f* are estimated, as before, by the graduated slide *g*, the fixed tube of which is attached to a foot-piece P, moveable in a bevelled groove in the base B; the whole may be hence withdrawn for a certain distance, if required, so as to place the disc *f* without the influence of the upper disc *m*.

The disc *m* is suspended from the fine silver thread passing over the balanced wheel W, by three threads of varnished silk, after the manner of a common scale-pan, so as to insulate it if requisite; it is connected with the ground in ordinary cases by a fine wire, terminating in a small hook loosely hung from the silver thread to the surface of the disc, as at *h h'*, fig. 1.

The glass vessel V containing the water, and counterpoise float, are here supported in a ring of brass, moveable in a brass tube attached to a sliding rod *q*. This rod is acted on by a nut and screw inclosed in a cylindrical piece *c* fixed to the horizontal plate carrying the wheel-work. Hence the water vessel may be elevated or depressed at pleasure, and the index *i* readily adjusted to zero, or any other required point on the arc.

4. These provisions enable us to operate with the instrument in the following way. Let it, for example, be required to estimate the attractive force between the plates *m*, *f* at any given distance, D, suppose ·6 of an inch.

We first bring the discs in contact so nearly as may be, and then set the graduated slider *t* at zero of its scale, by bringing it to coincide with the upper edge of the outer tube M. We then (having also set the slider supporting the insulated disc *f* at zero) either raise the tube *t* ·6 of an inch, or depress the slide *g* by the same quantity, or otherwise raise the upper and depress the lower disc by quantities making together ·6 of an inch; in either case the discs will be finally ·6 of an inch apart, measured between the opposed surfaces previously in contact. Under these conditions let either plate be taken insulated and charged, whilst the other is neutral and free. Suppose the lower disc *f* to be charged with a given quantity, and the suspended disc *m* free. Then the attractive force which ensues will cause the index to advance in the direction *o y* a given number of degrees, consequently the distances between the plates *m*, *f* will be diminished. Let the index be now brought again to zero by turning the milled head of the screw *c* so as to depress the water vessel V; then the force between the plates, whatever it be, is acting at ·6 of an inch. To discover the amount

of this in degrees, we discharge effectually the air and opposed plates m, f by touching them simultaneously with a bent wire. The force then vanishes, and the index declines in the direction $o\,x$. The amount of this declination is evidently the force in degrees at the given distance D = ·6 of an inch.

Do we require to obtain a force of any given number of degrees at a given distance, we first adjust the distance as before, the index being at zero of the arc, then depress the water vessel V until the index has declined the given number of degrees in the direction $o\,x$; we now continue to add small quantities of electricity to the insulated disc f until the index is again brought to zero, we have then in noting the quantity of electricity the required attractive force due to this quantity at the given distance*.

5. The general principles of this instrument, together with its mode of action, being now understood, I may merely observe, that although not available for the measurement of such minute forces as those applicable to the balance of torsion employed by Coulombe, it is still peculiarly delicate, and admirably well adapted to researches in statical electricity. Its indications depending on the force between two opposed planes operating on each other under given conditions, are reducible to simple laws, and are hence invariable and certain. The attractive force between the discs is not subject to any oblique action, is referable to any given distance, and may be estimated in terms of a known standard of weight.

6. It may not be unimportant to consider here the nature of the indications of this and similar instruments in electricity; in other words, what we really measure by means of such instruments.

This question is of considerable moment; for should the force between the discs be in any way influenced by a precarious distribution of the electricity, on or about their surfaces, and liable to become further complicated by the distribution on the surfaces of the conductors, and other bodies placed occasionally in tortuous connection with them, as in fig. 7, 8, 9, it would, perhaps, be impossible to say what we did really measure by any instrument such as that described; we should at least require the aid of a formidable analysis involving definite integrals of unknown functions to determine it: fortunately however such is not the case; the force between the attracting plates m, f, stands, as may be clearly shown by experiment, quite clear of any hypothetical distribution whatever of the electricity, with which the discs are charged, or with which any series of bodies may be charged in connection with them. Thus the general laws of electrical action arrived at in my former communications† remain uninfluenced by any new condition of the connecting rods, or other bodies of variable form, with which the attracting bodies may happen to be connected. The question, therefore, what do we measure? is very easily answered, as readily, in fact, as a similar

* There are some precautions essential to observe in the use of this and similar instruments, which will be apparent as we proceed.

† Transactions of the Royal Society for 1834.

question would be, if applied to the thermometer or any other instrument, the nature of whose indications are necessarily determined by experiment. Thus we observe that with double, treble, &c. quantities of electricity, either accumulated on the insulated plate *f*, or on any insulated conductor connected with it, we have invariably 4, 9, &c. times the attractive force indicated on the graduated arc, the distance between the discs remaining the same; no matter for the form of the charged bodies in connexion with the insulated plate *f*, or the form or disposition of any number of rods connecting them. Hence conversely, when the attractive forces are at distance unity, 4, 9, &c. times as great, then the respective quantities of electricity accumulated, under the existing disposition of the conducting surface, are 2, 3, &c. times as great; the quantity being as the square root of the indicated force. Similar observations apply to a variety of other quantitative measurements, of which this instrument is susceptible, as in the case of the attractive force communicated to the insulated plate *f*, when connected with a charged conductor of any given form, and which by experiment remains invariable, at whatever point of it the connection be made. Hence the general electrical intensity of such a conductor is always represented under any new disposition of its surface, as shown in my experiments on the capacity of rectangular plates, cylinders, spheres*, &c. These and similar facts deducible by experiment enable us, independently of all theory, to investigate by this electrometer certain electrical relations, such as that of quantity to surface, of intensity to figure, and the like, with accuracy and precision. This question then being disposed of, we may proceed to the further consideration of the elementary laws of electrical action, the subject of these inquiries.

7. Electrical attraction and repulsion, as commonly observed, are invariably attended, if not altogether preceded by other forces of a more elementary character, without the presence of which, neither of these interesting phenomena would probably ensue. These more primary actions we have, in accordance with the prevailing theories of electricity, classed under the general head of inductive actions. FARADAY has lately investigated the nature of these actions in the Eleventh Series of his admirable Researches in Electricity. The three following experiments exhibit some phenomena of induction not generally noticed, although the results are such as might be previously anticipated: the experiments however are still new of their kind, and very illustrative of what takes place, at the instant two bodies attract or repel each other by the agency of electricity.

Let a circular disc of gilded wood, about six inches in diameter, *a*, fig. 2, be suspended by an insulating thread of varnished silk from a common balance or the periphery of a light wheel W, the axis of which rests on friction wheels so as to allow it great freedom of motion; attach a delicate electroscope *r*, to this disc, and counterpoise the whole by a weight *p*. Let a similar disc *b*, insulated on the glass rod *g*, and having also an electroscope *r'* attached to it, be placed at any convenient distance

* Philosophical Transactions for 1834.

immediately under the former*: when the two discs are placed in certain electrical relations to each other, under a good insulating state of the air, the following phenomena may then be observed.

Exp. 1. The disc *b* being charged with either electricity, and opposed to *a*, insulated and neutral, we observe the electroscope *r* of the neutral disc begin to rise off its surface, whilst that of the charged disc *b*, already in a state of divergence, will tend to collapse. When these respective effects ensue, the suspended disc descends towards the charged disc.

Exp. 2. The two discs being both previously charged with opposite electricities, we observe, in opposing them as before, both the electroscopes, *r*, *r'*, begin to fall back, at which instant the discs appear to attract each other as before.

Exp. 3. The discs being now both charged with the same kind of electricity, we observe the divergence of the electroscopes *r*, *r'* increase; at this instant the suspended disc recedes from the fixed disc, being apparently repelled by it.

It may be further observed in the first experiment, that the operation of the neutral on the charged disc, as indicated by the electroscope *r'*, is greater when its superficial extent is increased. Thus, if it have a temporary connexion with an insulated conductor of twice or three times its surface; or otherwise, if it form the terminating surface of a hollow cylinder of the same diameter and of any given altitude, the collapsing of the excited electroscope *r'* attached to the charged disc will be more considerable. If it have a conducting communication with the ground, then, as is well known, its influence on the charged disc is, at a constant distance, the greatest possible. In many of these cases, however, the influence of the charged on the neutral disc is, on the contrary, less sensibly shown by the electroscope *r* attached to the latter, in consequence of the operation being extended to larger masses, and to more distant points.

8. The respective influences on the electroscopes just observed, and which precede, or *at least* accompany the attractive or repulsive forces between the discs, may be distinguished in the following way. In the case of the first experiment, the electroscopes indicate two inductive and simultaneous actions. One of these may be considered as a direct induction, the other as a reflected induction; supposing, as is not unlikely, that the induction of the neutral on the charged plate is entirely dependent on the electrical state excited in the former by the direct influence of the latter, by which an opposite force is induced, and which reacting on the charged disc, neutralizes a portion of its free electricity.

* The electroscopes *r*, *r'* may consist of light reeds, with pith balls at their extremities, counterpoised on a delicate axis of brass, set on points in metallic rings *r*, *r'*. These are fixed in the centre of the plates *a*, *b*. The reed and ball on the upper one is a little heavier than the counterpoise *r*; on the lower one the counterpoise is heavier than the reed and ball. Thus, in a neutral state, the balls lie parallel with the surfaces of the plates, and rise from them by repulsion, with the slightest force. It is only requisite to observe, that the pith balls should not in the neutral state actually *touch* the surface, but remain elevated within a very small distance of it, which may be readily effected by fixing a small slip of cork to the plate just under the reed. By this we avoid any adhesion of the ball to the plate, which interferes with the success of the experiment.

9. Pursuing this view we may further infer, as in fact may be shown experimentally, that similar inductions really tend to arise in both the subseqnent experiments 2, 3, notwithstanding the presence of the similar or dissimilar electricities; that is to say, inductive forces tend to arise in each disc, similar to those which would ensue if either plate were reduced to a state of neutrality, thus increasing the amount of the attractive forces in the case of the plates being charged with opposite electricities, and decreasing that of the repulsive forces when the discs are charged with similar electricities*: the laws of electrical attraction and repulsion therefore are intimately associated with these inductive forces; hence, as observed by FARADAY, it is requisite to examine rigidly the nature and operation of this wonderful influence.

10. There are many striking phenomena of electrical induction, which lead us to conclude that it is in some way dependent on the presence of an exquisitely subtle form of matter pervading bodies, which may become disturbed in them, and assume new states or conditions of distribution. The following experimental analysis goes far to place this beyond the limit of a mere hypothesis, and to confirm it as an elementary principle in electricity.

M, N, fig. 3, are two cylinders of gilded wood, about four inches in diameter and six inches long; the extremities of these cylinders terminate in thin slices, *a*, *b*, *c*, *d*; all the different pieces are insulated on slender rods of varnished glass, fixed in separate stands; these slide upon the pieces E, F by means of a groove and steadying pins in the stands; thus the false ends *a*, *b*, *c*, *d* may be either placed in contact with the cylinders M, N, or be otherwise placed at any given distance from them. The pieces E, F also slide in a similar way upon the base P P, so as to admit of the two bodies, M, N, being placed at any given distance apart.

Exp. 4. Electrify the cylinder M, and slide it to within any given distance of N; the latter will, as is well known, become electrified by induction, and the cylindrical slices *b*, *d*, if removed on their insulating rods, will be in opposite electrical states. But if before removal the charged body M be withdrawn, then the whole system returns to its previous state, and exhibits no electrical sign whatever.

Now it may be inferred, that if the peculiar condition of the extremities *b* or *d*, considered as portions of the body under induction, depended merely upon some peculiar affection of the particles of common matter, and not on some agency associated with them, then on removing the slices *b*, *d* forming the extremities, the forced state should vanish; for it is difficult to conceive how any principle of return to quiescence applicable to the whole body N, when removed from the influence of M, should not also apply to any part of it placed under the same conditions, *e. g.* to the thin sections, *b*, *d*, forming its extremities. But on removing the extremity *d* we find, as just stated, that the forced state remains.

Exp. 5. Examine in a similar way the thin slices *a*, *c*, constituting the extremities of the charged body M, having first determined the intensity of the charge previously

* Philosophical Transactions for 1836.

to opposing it to the neutral cylinder N. Then we find the intensity of the distant extremity *c* considerably diminished, and that of the proximate extremity *a* considerably increased; and this effect becomes the more apparent as the distance between the bodies is less, and will be strikingly shown if N be connceted with the earth*.

Exp. 6. Electrify the cylinders M, N, one positively, the other negatively; then on examining each as before, similar results will ensue; the distant extremities will show on removal less accumulation than the proximate ones.

Exp. 7. Electrify the cylinders, both positively, or both negatively, we have then an opposite result. The distant extremities will exhibit a higher positive or negative accumulation than the near ones.

11. These results, therefore, all appear to show, that some extremely subtle form of matter pervades bodies, which may be caused to change its state in them in respect of quantity. To determine the respective states of accumulative change in the bodies, I employed the electrometer just described, and examined them, either by their inductive influence on an area of equal magnitude, or by simply opposing the removed slices to the suspended plate *m*, fig. 1. at a constant distance, or by other methods not necessary to dwell on here. I obtained in this way some interesting results in respect of the relative quantities of electricity displaced at given distances, which will be noticed in another place (32.).

If we place at the extremity *b*, of the cylinder N, three or more consecutive insulated slices, insulating them on glass rods, in any convenient way as in fig. 4., and then proceed to examine the electrical state of these slices whilst under the influence of the charged body, the electricity of the distant extremity *d*, will frequently be found extending up to the last section *b*; and, contrary perhaps to what we might expect, the point to which the electricity of the distant extremity *d* extends toward *b*, will be greater as the intensity of M is greater and its distance from N less, as if the displaced electricity not being enabled to pass freely off in the direction *b d*, supposing M positively charged, was continually, as it were, bounding back or reverberating upon the extremity *b*, a fact which may be further observed in the following experiment.

Exp. 8. Oppose a cylindrical conductor D, fig. 5., about three feet in length and four inches in diameter, to an electrified cylinder C, charged with positive electricity. Test the state of different points of this cylinder D by touching it with a tangent disc of very small thickness. If we ascertain in this way the first point at which the electricity evinced is negative, we shall find on bringing the charged cylinder C within a less distance, or otherwise increasing its intensity, that the same point will become positive. The same thing occurs in increasing the extent of the opposed areas at the extremities of the cylinders, until at last the points immediately in the vicinity of the opposed end will become positive.

* In these experiments it is better to detach first the central portions M or N whilst under induction, when we wish to examine the state of the remaining slices *a*, *b* or *c*, *d* forming the extremities.

Exp. 9. Detach in fig. 4. the central part N and extremity *d* of the cylinder N, and remove the charged body M. Then if the extremity *b* consist of two or more sections, *b*, *r*, *s*, these sections will evince negative electricity, M being positively charged; but if after detaching the central mass N we allow the charged body M to remain, and then take away the further slice *s*, this slice, which under the former arrangement evinced negative electricity, will now evince positive. There must consequently still remain a portion of electricity sufficient to electrify the remote section positively, although not equivalent to the negative state of the three slices taken together, and removed from without the influence of the charged body.

12. Since then the negative state of an indefinitely thin slice *b*, immediately opposed to the charged body, may be supposed to depend on the electricity displaced from it, and collected in the detached central mass N, we may conclude, in accordance with the well-known fact, that this negative state will be the greatest possible when the electrical capacity of N is indefinitely great, that is to say, when it is connected with the ground, and whilst the influence of the charged body M is still operating on it. The near surface *b*, therefore, of a free neutral body, N, fig. 3, under the induction of a body, M, positively charged, is greater than would be apparent upon the whole body after cutting off its connexion with the earth.

The inductive action, whatever it be, which thus takes place between a charged and neutral body, does not appear to be in any degree influenced by angular divergence, but is exerted equally in every direction from the point at which the induction first commences; this may be inferred from the following experiment.

Exp. 10. A cylindrical conductor, N, figs. 6, 7, was so constructed as either to constitute a single straight line, fig. 6, or assume a rectangular form, as in fig. 7. It consisted of two straight cylinders of gilded wood, each about a foot in length, and three-fourths of an inch in diameter, united to an intervening ball N by means of short brass pegs. In this way the two cylinders could be easily placed in one straight line, as in fig. 6, or at right angles to each other, as in fig. 7. Under this condition one extremity, *f*, fig. 6, was placed in contact with the insulated ball *f* and disc of the electrometer, fig. 1, and the opposite extremity united to a light disc *c*, of about three inches diameter. The inductive force was impressed upon this last by a charged cylinder, M. The distance, *c a*, and quantity with which M was charged being the same, it was easy to discover whether any difference arose in the attractive force on the electrometer at the extremity *f* when the conductor was bent at right angles, as in fig. 7, or otherwise allowed to form a straight line, as in fig. 6. No appreciable difference, however, was observable in these different dispositions of the conductor N. Thus the distance *c a* being one-fourth of an inch, and the charge the same, the electrometer indicated in each instance ten degrees, the discs *m*, *f* being also one-fourth of an inch apart. The quantity and distance *c a* was varied, but a similar result ensued. It may be hence inferred that the force impressed upon the disc *c* is propa-

gated in the conductor equally in all directions, thus exhibiting in a remarkable way one of the primary laws of fluids.

13. Since these facts furnish some evidence in favour of the conclusion that electrical phenomena result from certain changes in the distribution of a subtle kind of matter associated with the particles of bodies, it may not be unimportant to examine the laws of these changes in the cases of induction and attraction above mentioned.

It must be apparent by experiments 4, 5, 6, figs. 3, 4, that in the ordinary attractive force between a body positively charged with electricity, and a neutral body N in a free state, three actions arise claiming particular notice, viz. a receding of the natural electricity of the neutral body, from the points nearest the body charged positively; a passing of electricity from the remote points of the positively charged body toward the neutral body; lastly, a tendency of the opposite electrical forces to come together and enter into a species of union; which last condition seems to be the immediate cause of these two bodies approaching each other, all impediment to motion being removed.

14. With a view of discovering some of the laws of these induced changes, I resorted to the method represented in Plate IV. fig. 8, in which A, B are two flat discs of wood covered with tin foil, insulated on varnished glass rods, A *d*, B *p*. The upper disc A is connected with the insulated disc *f* of the electrometer E, and is supported by the arm R *d* fixed to the glass or wood column R T. The lower disc B can be set at any required distance from A by the graduated slider S, and retained there by a stop screw, S. The rod *d* A also is moveable with friction through a compressed collar of cork at *d*, by which it can be elevated or depressed for the more perfect adjustment of the contact of the plates A, B, when the slide S is at zero of its scale.

Exp. 11. The distance, *a b*, between the plates being made = ·3 of an inch, and the plate B connected with the earth, a charge was accumulated on A, indicating on the electrometer two degrees, the discs *m*, *f* being set at ·4. The plate B was now depressed to twice the distance, so as to make the distance *a b* = ·6 of an inch. The electrometer now indicated at the same distance of ·4, eight degrees. By making *a b* = ·9, or three times the first distance, the electrometer had advanced to eighteen degrees. The march of the electrometer therefore was directly as the squares of the distances between the plates.

15. Now it is clear in this experiment that the quantities of free electricity in the upper plate were inversely proportional to the distances between the opposed surfaces, the quantity by the demonstrated law of the electrometer (4.) being as the square root of the indicated attraction; hence the force or influence of the lower plate, that is the reflected induction (8.), is, if measured by the quantities of electricity it ceases to hold in equilibrio, as the distance *a b* between the plates A, B inversely; if measured by the indication of the electrometer, inversely as the squares of this distance.

16. Exp. 12. The former experiment relates to the influence of distance; it may

not be unimportant therefore to observe the effect of quantity under similar circumstances. In this experiment, then, the distance *a b* was first fixed at ·4 of an inch, and four measures of electricity deposited on the plate A. The indicated force with this quantity amounted to 3°. When eight charges were placed on A, that is double the former, the indicated force amounted to 12°, or four times the former, and so on in the same ratio of the square of the number of charges, up to the limit of the action of the electrometer, which is the law above mentioned, and shown for the coated jar in my first series of papers*.

17. I confirmed this result by making the distance $a\ b = \cdot 8$, and communicating to the insulated plate the same number of charges. The electrometer now indicated 46°, being little different from 48°, the number which should appear by the former experiment. The plates and electrometer discs were now perfectly discharged, and the same eight charges deposited on A when the distance *a b* was reduced to ·2 or one quarter. The electrometer now indicated 3° only, or $\frac{1}{16}$th of the former force.

18. The reflected influence of the lower plate therefore is such, as to hold quantities of electricity in equilibrio directly proportional to the quantity with which the insulated body is charged.

Exp. 13. I extended these experiments to opposed plates whose areas were less than the former, but equal, and found, as in the former experiments with the Leyden jar, that the quantity and distance being constant, the indicated force was as the squares of the opposed areas inversely. Thus, when the areas of the plates were doubled, the force was only one-fourth as great.

19. We cannot by this method deduce any accurate result for plates of unequal area, as in my former experiments on attraction†, since the charge expanding over the whole of the upper disc, and also the electrometer, it does not admit of being neutralized throughout, hence the influence of the opposed portions only is not apparent; neither will the laws above mentioned be rigidly exact, if we charge the insulated plate A without the influence of the opposed plate B, since in this case also the electrometer discs receive a maximum of charge at once, which cannot be subsequently diminished so as to show the action of the neutral plate B. But in accumulating the charge under the influence of B, the electrometer charges gradually, and with the electricity not held in equilibrio by the lower plate.

20. In the three preceding experiments the neutral disc B, had a free connexion with the ground. We shall now take it insulated.

Exp. 14. The plate A being charged under the influence of B as before, at a distance of ·2 of an inch, indicated by 4° of the electrometer with the discs *m*, *f* at ·5, the conducting connexion of B with the ground was removed, so as to insulate it. In this case the induction upon B was the greatest possible at the given distance ·2. The plate B was now depressed ·2 and ·4 of an inch further, so as to obtain double and quadruple the first distance successively. The march of the electrometer in this

* Transactions of the Royal Society for 1834. † Ibid.

case was no longer as the squares of the distances *a b*, as in Exp. 11, being now as the distance; thus at ·2 the force was 4°, at ·4 = 8°, at ·8 = 16°.

The following table exhibits the results of the comparison of the insulated and uninsulated state of the plate B at other distances and with other charges.

TABLE I.

Insulated at ·3.		Uninsulated.	
Dist.	Force.	Dist.	Force.
·3	3°	·3	3°
·6	7	·6	12
·9	10	·9	26

The approximation to the laws above mentioned are here very close.

It is then apparent from these results, that by limiting the electrical capacity of the opposed plate, we fix the direct inductive action up to a certain limit; hence the subsequent effect is due to change of distance only, and is in a simple inverse ratio of the distance. FARADAY has shown in the Eleventh Series of his valuable Researches in Electricity, since this experiment was first made, in what this effect of change of distance consists; he observes, (sec. 1303,) "there is perhaps no distance so great that induction cannot take place through it: but with the same constraining force, it takes place more easily, according as the extent of the dielectric is lessened," &c. &c.

21. Exp. 15. A plate of glass very dry and varnished being opposed to the plate A, and a charge accumulated as before, no change was perceptible on altering the distance, or on the removal of the glass; we may hence infer, that a perfectly non-conducting substance is insensible of any new electrical state, by simple induction under common circumstances.

Exp. 16. The plate B being insulated and opposed to A, the difference on the electrometer after removal was still very small, and at moderate distances of ·2, ·3 of an inch quite inappreciable. These differences, however, became greater by increasing the thickness of the plate, or by allowing a small conducting rod to project from it.

We may, therefore, further infer, that in an insulated conducting disc indefinitely thin, the inductive capacity is indefinitely diminished*.

22. Electrical attraction then, is evidently a complicated operation, and may not unfrequently give rise to results apparently of an anomalous character. The uniformity of the force depending on a perfect accomplishment of the inductive changes above mentioned, should these be in any way limited, or interfered with, the force may appear to vary, or be also limited in the law of its action to certain distances, as is apparent in the following experiments.

* The case must not be taken as identical with that described by FARADAY (1295.), we are here speaking of an insulated disc, not a disc connected with the earth: no sensible thickness is then required, as already shown by the suspended disc of the electrometer.

Exp. 17. When two circular discs *m f*, fig. 1, were opposed to each other, the suspended disc *m* being perfectly insulated and thin, and the lower disc charged positively, little or no attractive force was observable at ·3 of an inch distance. At ·2 of an inch the force amounted to about a degree. On touching the neutral disc with a conducting rod the force appeared to be indefinitely increased, not being under the same charge and distance measurable by the instrument.

Exp. 18. A varnished disc of glass being substituted for the disc *m*, the force was not appreciable at any distance.

Exp. 19. The opposed discs being charged, one positively, the other negatively, and to as nearly the same degree as possible, the forces were observed corresponding to various distances by the process above described (4.); they were as the simple distance inversely, or very nearly so. Now it is to be observed in this case, that the discs being thin, the positive and negative accumulations, as in Exp. 14., were already the greatest possible, or very nearly so: all subsequent inductive change was therefore precluded, and hence the increase of force was due to change of distance only, or according to FARADAY, to the intervening dielectric particles being lessened.

Exp. 20. The lower disc being charged positively and the upper plate allowed to remain neutral and free (4.), the force within given limits was as $\frac{1}{D^2}$, but at near distances as $\frac{1}{D}$.

In this case the lower disc *f* having a limited thickness and charge, is not fully susceptible of the reflected induction at all distances; hence this force is impeded as before, and the conditions at last approximate to those of the permanent positive and negative states in the preceding experiment.

Exp. 21. The lower disc *f* being connected with a charged jar or coated plate either of air or glass, as in figs. 8 and 9, and the suspended disc *m* placed in connexion with the ground, the forces were as the squares of the distances inversely at all the distances at which the experiment could be tried.

It is to be observed here, that the inductive capacity of each surface was indefinitely increased, whilst the quantity of electricity accumulated might also be considered as indefinitely great in respect of the charged surface.

23. The generally received law of electrical attraction would, by these phenomena, appear to be rather a result of the conjoint operation of two elementary actions than a simple law, such as that observable in the action of forces supposed to emanate from a centre, since it is not demonstrable, except under given conditions of induction peculiar to the attracting bodies. When the positive and negative states are fixed and invariable, the attraction between the plates, as found by experiment, is really in a simple inverse ratio of the distance.

Exp. 22. With a view of examining this result more rigidly, and disengaging the electrical particles so far as possible from all association with a conducting substance, I procured two thin circular plates of glass, about ·6 of an inch diameter, and having

given them temporary coatings of gilded wood, as in fig. 10, I charged each with a given quantity. The coatings were now removed, and the charged glass plates transferred to the electrometer with the positive and negative surfaces opposed to each other, as at *m f*, fig. 1. The lower plate in this case was supported on a slightly curved glass, similar to a common watch-glass, so as to avoid the presence of any conducting substance, and three silk lines of suspension attached to the upper plate by a little sealing-wax. In this experiment we may conceive the force to result purely from the action of the opposite electricities, which may in this case be considered as fixed and incapable of any further change, since by the law of the coated jar no electricity can be added or taken from one side without a simultaneous corresponding change on the other, hence one side only may exhibit free electricity. The glass plates themselves also, not being susceptible of induction (Exp. 15.), cannot be supposed to share in the attractive force, whilst the remote surfaces of each plate are virtually neutral. Under these circumstances the force varied very rigidly as the distances between the plates inversely, at all distances at which the experiment could be tried.

24. The relations of the inductive to the attractive force becomes under this view an interesting subject of inquiry in electricity. I endeavoured to examine still further by a careful series of experiments the general laws of these forces, and succeeded in arriving at many results calculated to throw additional light on the nature of electrical action.

Two discs *m*, *f*, fig. 11., were opposed to each other, as explained in the Society's Transactions for 1834, p. 220, that is to say, the disc *m* was suspended from one arm of the balance B, whilst the disc *f* was connected with a coated jar; the attractive force between the discs at various distances being measured by weights placed in the scale pan *p*, and the quantity of electricity estimated by the unit jar *u*.

Exp. 23. The suspended disc being very perfectly insulated by varnished silk lines, the force of attraction at a constant distance was examined with a given quantity of electricity in a very dry atmosphere, and subsequently compared with the force under the same conditions of quantity and distance, when placed in a free state by a small connecting wire accurately balanced and hung from the point *g*; the difference, as may be anticipated, was very great. In the insulated state, it required sixty charges before the force was equal to one grain at a distance of ·2 of an inch. In the free state, three charges only were requisite to raise one grain at ·2.

Now we have before seen, that the force between two attracting discs, is as the square of the quantity of electricity communicated to the charged body; the force, therefore, in the free state with sixty charges, could this quantity be accumulated and retained, would have amounted to 400 grains; or otherwise taking only three charges in the insulated state, it would have been only the $\frac{1}{400}$th of a grain. The force therefore in these two states may be taken as inversely proportional to the square of the number of charges. Hence the force between the plates was greater in the free state in this particular case, in the ratio of 400 : 1.

25. Exp. 24. With a view of observing the rate of increase of the attractive force as the capacity of the neutral body was caused to increase, I placed successively on the suspended disc *m* a series of rings of gilded wood, as in fig. 13, so as to increase the thickness from ·1 of an inch to two inches: the results are given in the following Table.

TABLE II.

Thickness	·1	·2	·4	·6	·9	1·2	2·0
Charges	60	50	40	30	24	20	16
Force compared with the force when free	400 : 1	277 : 1	177 : 1	100 : 1	64 : 1	44 : 1	28 : 1
Force of sixty measures reduced to grains	1—	1·44	2·25	4	6·2	9	14

The amount of charge for the first experiment, both in the insulated and free state, was as near as could be determined. The beam dropped in the latter case with something more than three charges, hence the force must be assumed as something less than a grain. In the insulated state it was not easy to arrive at the precise number of charges, although the variations were not considerable: sixty charges of the unit measure, however, corresponded upon a mean number of experiments, to the same force, about one grain. If we assume the force for thickness ·1 to be something less than a grain, let it for example be taken at ·7, then the force as expressed in the lower line would increase nearly as the thickness or altitude of the cylinder, which is not a little remarkable.

Exp. 25. I followed out this result by examining the force upon three cylindrical conductors, A, B, C, fig. 12, whose altitudes were 1·5 inches, three inches, and six inches, that is, as the numbers 1, 2, 4, and having terminating plane surfaces equal to that of the plane disc *m*, fig. 11. These being suspended successively from the balance, the force, taken in a free state, amounted as before to one grain, with rather more than three charges, being the same as the simple disc taken in a free state; when taken insulated, the forces varied, and were nearly as the altitude of the cylinders directly. Now on referring to the induced force, I found that all this time the inductive charges upon the disc and cylinders continually increased with the thickness. Thus when the two extremely thin slices, *b*, *r*, fig. 4, were employed alone, and the experiment taken as before in Experiment 4, the opposite electrical state of the near slice was extremely small; whereas on increasing the number of slices, and finally the extent of the body N, the induction continued to increase rapidly, and nearly in proportion to the length of N, up to a certain limit.

26. The attractive forces with these cylinders taken insulated, were found to be as the square of the number of charges accumulated, and inversely as the distance,—a result I subsequently confirmed, and found general in all cases of attractive force

between a charged and insulated neutral body. The following Table, abridged from experiments too numerous to detail here, exhibits numerical examples of this result, the charges and distances being given for forces of 1, 4, &c. grains.

TABLE III.

Distance of surfaces.	A. 1·5 inches.		B. 3 inches.		C. 6 inches.	
	Charges.	Force.	Charges.	Force.	Charges.	Force.
·2	20	1	15−	1	9+	1
·2	40	4	30−	4	19	4
·4	40	2	29	2	18+	2

It may be here seen that the force is as the square of the quantity divided by the distance, and may be hence represented by the general expression $F = \frac{Q^2}{D}$. We may further, by this result, deduce the force which would arise, in each case, with a unit of quantity at a unit of distance, and hence arrive at the comparative force for each altitude, A, B, C. Thus in the first line, if we take twenty charges as a unit of quantity throughout for A, B, C, we obtain, taking as before the force which would arise as the square of the number of charges (4.), the following result very nearly:—

Cylinder A. 1·5 inches high. Force 1.
Cylinder B. 3 inches high. Force 2.
Cylinder C. 6 inches high. Force 4.

By which we perceive that the forces are as the altitudes, or very nearly, the approximations being evidently very near, thus confirming the result already arrived at (25.). It is not unlikely that in this case we remove, by increasing the length of the cylinder, the similar electricity to a greater distance from the charged body; and hence the force between the dissimilar electricities is less disturbed, so that we may in this case be merely measuring the difference between the attraction of opposite electricities and the repulsion of similar ones.

27. Exp. 26. I endeavoured to observe the relation between the attractive and inductive forces more directly in the following way. Having interposed a cylindrical conductor, B, fig. 14, about three inches high, between the charged plate *f* and the suspended plate *m*, and noted the distances *n m* and *b f*, the number of charges was determined corresponding to a given induced force in B, as measured by the effect on *m*. The intermediate cylinder was now attached to the suspended disc *m* by varnished silk lines, as in fig. 15, and both suspended from the balance, so as to ascertain under precisely the same conditions of distances, *m n*, *b f*, and quantity of charge, the amount of the attraction between *b* and *f*.

By this method we obtain, 1° a measure of the induction, 2° of the corresponding attraction; and may hence compare these forces under the same or certain relative states; the distances *b f* and *m n* being either constant or variable. I examined in

this way the relative forces of induction and attraction in a great variety of cases, and obtained the following general result, viz. the attractive and induced force was either precisely the same or otherwise in the same ratio, or otherwise reducible by the application of the general laws above mentioned (4.) to the same numerical value. The following Table contains the respective forces of attraction and induction, at given distances, &c. between the opposed bodies *b*, *f*, which may perhaps be quite sufficient as an experimental illustration.

TABLE IV.

Distances.			Induction.		Attraction.	
	Charged plate. Dist. *b f*.	Suspended disc. Dist. *m n*.	Quantity.	Force.	Quantity.	Force.
A.	·2	·2	9−	1	9	1
			17	4	17+	4
			27	9	26	9
B.	·2	·4	19+	1	10	1
			40	4	21	4
			60	9	32	9

28. We perceive in this Table that the first forces (A.) of attraction and induction correspond to the same quantity of electricity, or very nearly, and are therefore to be considered the same. In the second set of forces (B), where the distance of the suspended disc *m*, by which the induction is estimated, is increased, the number of charges corresponding to the inductive force is greater. Still the forces of induction and attraction are in the same ratio, as compared with the quantity of electricity. Thus we have, nearly,

Ind. quant. 19 + : Att. quant. 10 : : Ind. quant. 40 : Att. quant. 21

or

Ind. quant. 40 : Att. quant. 21 : : Ind. quant. 60 : Att. quant. 32.

But in comparing these numerical values we may reason thus: since the quantity and distance for the forces (B) differ, let them be reduced by calculation to a unit of distance and a unit of quantity; let the unit of distance be ·2, and let the unit of quantity be about nine or ten charges, as in the first line of the forces A; then taking quantity 19 + corresponding to inductive force 1, we should have for 9·5 charges, that is, half the number of charges, only one-fourth of a grain (4.); but in reducing the distance ·4 also to one half or ·2, this force would be again quadrupled, and would become one grain as before, supposing the force on the suspended disc *m* to vary as the square of the distance inversely, which by experiment it was found to do in this case sufficiently near. If we pursue the same course with the remaining experiments on the inductive forces (B), a similar result will be arrived at. Thus we may reduce the forty charges to twenty-one, the quantity for the attraction, and take the distance ·2 instead of ·4, we have then similar forces of four grains. The real state of this and similar cases, is simply this. In consequence of the increased

distance of the suspended plate, twice the number of charges accumulate before the same induced force is shown by the electrometer, although the induction is really doubled; hence in suspending B, fig. 15, the attraction takes place with half the number of charges, that is, half the induction, being the same as before (A).

29. These experiments require precision in the adjustment of the respective distances, and in the measurement of the respective quantities; the approximations may therefore be considered as being very close, especially when we take into the account the many delicate manipulations of a general character peculiar to electrical experiments. It is, however, easy to discover when the result is disturbed by errors of observation, or by accidental variations in some of the circumstances attendant on a long series of experiments. Thus in the preceding Table (B) it is quite apparent that the number of charges corresponding to the induced force would be double of those corresponding to the attractive force; and that the difference of a few sparks of the unit measure arises probably from some minute variation in some of the conditions of the experiment. I tabulated many hundred results; some of them were perfectly coincident and exact in the numerical values above given, others less so; but I had no difficulty in observing the laws above mentioned throughout.

30. It may not be amiss to observe, that, as a preliminary step, the influence of the upper disc *m*, fig. 14, was examined experimentally, since the active inductive force may be supposed to proceed more easily in proportion as this disc in a free state is placed nearer to the body B under induction. I had not, however, much trouble in simplifying the conditions of the experiment. The force between the interposed cylinder B and the disc *m*, being, within certain limits, as the squares of the distances *m n* inversely, and as the square of the number of charges directly; I was consequently enabled to select such distances and forces as were best adapted to the particular case. The influence of small variations in the distance *m n* on the inductive susceptibility of B was thus avoided. Thus in the experiments given in Table IV. (B), the intermediate cylinder underwent nearly as much inductive change with the given quantity, when the disc *m* was ·4 distance, as at ·2, as appears by the reductions just given, and by the attractive forces being the same, or very nearly, the difference in the number of charges being small. Thus in the attractive forces (A) the charges were 9, 17 +, and 26; in the attractive forces (B) they were 10, 21, 32. As the numbers refer to small measures of the unit jar, the differences upon the whole quantity are not greater than might be expected. I have obtained other results, in which the numbers were nearly alike. The experiments here recorded, however, better represent the average results.

31. The influence of a free neutral disc thus opposed to the terminating plane surface of an insulated cylinder, B, fig. 14, being such as to increase the inductive capacity of the cylinder, we cannot always estimate by this method the corresponding inductive and attractive forces. Thus in the case of the three cylinders, Exp. 25, Table III., in which the attractive force was as the altitude, we could not by this

method estimate the inductive change, since the influence of the suspended free disc would be such as to give each the same inductive susceptibility at the lower attracting surface. It is, however, to be observed, that the attractive forces are, there also, the same as in the case of taking the cylinders in a free state. In this case, therefore, the induction must be measured by a process similar to that resorted to (10.) Exp. 4.

32. Considering these results of consequence to a true theory of electricity, I thought it desirable to institute other methods of experiment, so as to expose more completely the operation of the inductive process, and at the same time verify the preceding deductions. With this view I resorted to the method represented in figs. 16 and 17, in which S T represents a cylindrical wood column attached to the foot-piece W, or substituted for the part P *g f*, fig. 1. This column carries the brass sliders S T. The slider S sustains the light tubular brass rod S V' V, and smaller sliders V V'; these support, by the glass rods V' A, V B, the conducting cylinders A, B. In like manner the sliding piece T sustains the thin slice *f*, fig. 16, forming a false upper end to B; or otherwise, if this slice be placed at the lower extremity of B, as in fig. 17, it is supported by the slider V, whilst T carries the body B. Now it is easy by this arrangement to remove, by the slider S, the bodies A and B, fig. 16, simultaneously, and without interfering with distance *a b*, so as to leave the thin slice *f* in operation on the electrometer disc *m*. Hence, if we suppose in this case, that A is charged with a given quantity, and B neutral, we may measure by the electrometer disc *m* the result of the direct inductive force upon *f*, apart from the bodies A and B, and this may be done without the result being influenced by the presence of the electrometer disc *m*, which may be temporarily turned aside during the previous process. We may also in fig. 17, supposing B charged and A neutral, examine the reflected induction by withdrawing A and the false end *b* simultaneously, and finally estimating by the electrometer disc *m*, the proportion of the whole charge abstracted by the influence of A at different distances. We may, in fact, obtain any required complicated mechanical arrangement peculiar to this kind of research, and arrive at a very complete experimental analysis of the reciprocal inductive action between the two opposed bodies, under a variety of new conditions*.

Exp. 27. The body A, fig. 16, being charged with a given quantity and placed within ·2 distance of B, the force upon the electrometer disc amounted to 20°; the distance *m f*, of the latter being ·5 of an inch. The cylinders A and B were now withdrawn simultaneously, leaving the false end *f* in place. The force amounted now to 8° only. This process was repeated with the distance $a\ b = \cdot 4$, in which case the remaining force was 4°, or one half the former. The induction, therefore, as expressed in degrees of the electrometer, was as the distance *a b* inversely, and, consequently, the respective quantities of electricity left on the false end *f* as $\sqrt{1} : \sqrt{2}$ (4.). The quantity of electricity displaced, therefore, varied as the square root of the distance

* To prevent the exposure of any additional surface on the removal of the false end, the cylinders were hollowed out for about an inch within the extremity, upon which the false end rested.

a b, being the law arrived at in the preceding experiments (29.). I extended this to distances ·6 and ·8, and still found the force in degrees as these distances inversely.

33. Exp. 28. The object of this experiment was to discover the resulting negative state induced in B under the influence of A, by touching it with a conducting wire and then removing A. With this view A was charged as before, and B rendered negative at the distance ·2; after this, A was withdrawn and discharged, and the negative force observed, which amounted to 20°, being the same as the previous induced positive state. This being repeated at distances ·4 and ·8, the respective negative forces were 10° and 7°, being in an inverse ratio to the distances, as before, and identical in this case with the previously induced positive forces, these last being observed upon the whole mass B whilst under the influence of A.

I verified this experiment by charging A so as to induce 5° and 20° of positive charge in B, that is to say, attractive forces in the ratio of 1 : 4, corresponding to quantities in the ratio of 1 : 2 (4.). On rendering B negative at the same constant distance *a b*, the forces were still 5° and 20° of negative charge. I found also on further repetition, that the same result ensued in multiplying the number of measures simply. Thus the negative force induced in B by three measures, being 10° at ·4 distance, six measures induced 40°, or very nearly; when therefore the charge in A is doubled, the induced negative state is also doubled in respect of quantity, since the corresponding degrees of the electrometer are quadrupled (4.). The following simple expressions may, therefore, be taken to represent this result: ind. $= \frac{Q^2}{D}$, if valued in degrees; or ind. $= \frac{Q}{\sqrt{D}}$, if valued in quantity.

34. Exp. 29. This experiment applies to the quantity of electricity influenced in B when charged by the opposed body A taken neutral and free, that is to the reflected induction (8.). The general arrangement is represented in fig. 17, in which the false end *f*, fig. 16, is placed at *b*, so as to detach it by the slider S, together with the neutral body A, by which we may discover how much of the whole quantity with which B is charged, considered as a unit of quantity, is determined as it were upon the near surface *b*, as also the respective quantities of electricity in operation between the opposed planes *a*, *b* at different distances. In conducting this experiment, the quantity with which B was charged $= m$, was first observed in degrees of the electrometer and taken as a unit of quantity, A being turned aside. Secondly, the false end *b* was removed, and the remaining quantity $= n$ also observed in degrees, so as to determine the decrease due to the removal of *b* alone $= t = m - n$. Thirdly, the false end *b* was replaced, the original charge made complete to 20° $= m$, and the body A in a free state opposed to B at a given distance. Lastly, *b* and A were under this condition withdrawn together and the remaining quantity $= p$ observed in degrees, so as to obtain the comparative quantity actually existing in *b* whilst under the influence of A $= m - p$, as also the comparative quantity determined upon *b* by induction $= (m - p) - t$: putting $m - p = S$, we have the reflected induction in quantity

$= S - t$. Thus the whole quantity m being taken as unity or 1, the electrometer indicated 20° when the disc m was ·4 of an inch distant from the upper plane surface of B, the cylinder A being withdrawn. The false end b being now removed, the electrometer indicated 12°·5: the quantity remaining therefore $= n$ was ·79 since (4.)

$$1 : n :: \sqrt{20} : \sqrt{12{\cdot}5}$$
$$:: 4{\cdot}472 : 3{\cdot}535$$

hence $n = {\cdot}79$. The decrease, therefore, due to b alone is in this case $= 1 - {\cdot}79 = {\cdot}21 = t$, hence about $\frac{1}{3}$th of the whole of this particular charge was collected in the extremity b.

Now when b was withdrawn under the influence of A at distance ·2 then 3°·5 only remained: this corresponds to quantity ·42, nearly $= p$, since we have (4.)

$$1 : p :: \sqrt{20} : \sqrt{3^{\circ}{\cdot}5}$$
$$:: 4{\cdot}472 : 1{\cdot}872.$$

The decrease, therefore, due to b and A together is $1 - {\cdot}42 = {\cdot}58 = m - n = S$: hence about six-tenths of this particular charge was collected on the near surface b at distance ·2, and the quantity therefore determined there by the reflected induction is ${\cdot}58 - {\cdot}21 = {\cdot}37 = S - t$. These respective elements for different distances between the opposed surfaces of A and B determined as in the above example, are given in the next table.

TABLE V.

Original charge 20° = quantity 1 = m. Remaining deg. 12·5 = quantity ·79 = n. Quantity on b alone = ·21 = $m - n = t$.				
a.	*b.*	*c.*	*d.*	*e.*
Distance.	Final Degrees.	Quant. = p.	Quant. = S due to A + b.	Quant. S − t due to Ind. of A.
·2	3·5	·42	·58 +	·37 +
·3	5·5	·53	·47	·26 −
·4	7 +	·59	·41	·20
·5	8	·63	·37	·16
·6	9 +	·67	·33	·12 +

35. It may be inferred from this table, columns d and e, that the quantity of electricity (column d) accumulated in the near extremity b of the charged cylinder, fig. 17, was as the square root of the distance from the opposed surface of the neutral body, whilst the quantity displaced by induction of A (column e) is nearly in the inverse ratio of the distance. The numerical results are not everywhere rigidly exact, but they evidently point out these laws, and are in some cases extremely close. Thus in column e we have, taking the distances ·2 and ·6, which are as 1 : 3, the inverse quantities ·12 + and ·37 +, which are as 1 : 3; so also in column d we have corresponding to the same distances the quantities ·58 and ·33, which are to each other as the $\sqrt{3} : \overline{1}$.

36. The result shown in column *d* is strikingly in accordance with that arrived at by a former and distinct method of experiment (15.); by which it was found, that the reflected induction, if measured by the quantities of electricity the neutral body ceases to hold in equilibrio at different distances, is as the simple distance inversely. The result also of column *d* corresponds with the law just found (Exp. 27.) for the direct induction on the neutral body. The experiments, therefore, are clearly consistent one with the other.

When different charges were taken, and the distance *a b*, fig. 17, made constant, the numerical values varied with the charge, the forces being as the square of the charge expressed in degrees of the electrometer. This was at least observed for all the charges which could be fairly brought within the experimental range of the instrument.

37. The application of these results to the phenomenon of attraction by electrical agency, is not a little interesting; they in fact help us to a more complete perception of this wonderful operation. We may perceive, for example, that when a conducting substance charged with electricity attracts another conducting body in a free neutral state, the electrical distribution is so disturbed in each as to cause an accumulation in the opposed parts *a*, *b*, fig. 17, inversely proportional to the square roots of the distances. By the laws of electrical action, therefore, before explained, (4.) and (22.), Exp. 18, we have eventually the whole force, as shown by the electrometer, as the squares of the distances inversely. For let a unit of force at a unit of distance be given; suppose, for example, at the distance one inch; the force between *a*, *b*, fig. 17, was five degrees: let the distance be now taken $= \cdot 5$, or one half the former, then the quantities of electricity in the opposed surfaces will be as $1 : 1\cdot 414$, that is, as $\sqrt{1} : \sqrt{2}$ inversely (32.) (35.); but the force is as the square of the quantity. The force therefore with this change would be twice as great at the distance unity; but it varies also with the distance (Exp. 18.); hence at the distance ·5, or one half the former, it is again doubled; that is to say, the forces are as 1 : 4 when the distances are as 2 : 1, being a result of two simple laws taken conjointly, as already noticed (23.): similar reasoning applies to distances $\frac{1}{3}, \frac{1}{4} \ldots \frac{1}{n}$th, &c. When, as we have before explained (22.), the inductive changes are small, and admit of the quantity at the distance unity being taken as constant, then the force is as the simple distance inversely, depending solely on the closer approximation of the electrical particles (Exp. 18), or according to Faraday, on the diminution of the number of particles of the dielectric through which the force operates. Thus in the case of the attractive force between a charged and insulated neutral conductor, the induction may be very inconsiderable in respect of the whole charge. We observe in the free state, Table V. (*e*.), where the inductive force is the greatest possible, that at the distance ·4 not above one-fifth of the whole charge was determined towards the opposed surface; now these additions by the reflected induction of an insulated body may not greatly influence the result,

especially within certain limits; we may, for example, have so little as the $\frac{1}{100}$th and $\frac{1}{200}$th only of the whole charge disturbed at distances ·4 and ·2, which slight addition to the already existing accumulation in the opposed surface may not materially affect the electrometer: hence the force may vary nearly as the distance inversely. This, together with the circumstances above given (23.), may perhaps account for the difference in the law of the force, as regards the distance, between the insulated and neutral state. There are, however, probably, other conditions of induction already mentioned (26.) applicable to this case, and which the masterly investigations of FARADAY bid fair to evolve: every one conversant with this interesting branch of science must necessarily allow, that never before has it been enriched by results so comprehensive and momentous as those contained in his several series of researches. It is also to be further considered, whether at small distances, although the force between two particles should be as $\frac{1}{D^2}$, still the force between the plates may be as $\frac{1}{D}$ simply, the whole attraction being found by a double integration, which sums all the forces, every particle of A being supposed to attract every particle of B.

38. The preceding facts lead us to refer every case of attraction in electricity, in a non-conducting or insulating medium, to the conditions of that peculiar combination of electrics and conductors, termed the Leyden jar, or coated pane, a combination consisting of an insulating body, interposed between two conducting surfaces. Now it is admitted that the charge which this combination can receive, is quite independent of the thickness of the opposed conductors, or of any hypothetical distribution upon them, or other bodies in connexion with them. Thus the charge which the electrical jar can receive under a given intensity, is as great when the coatings are mere films of metallic leaf, as when a solid mass of metal; the only condition essential to the perfect success of the experiment, is the free state of one of the coatings, and the complete insulation of the other, as also their close approximation. The action of the coatings in this case is reduced to one of these cases already given (16.), in which the distance between the bodies is constant, and the quantity of charge variable; the only difference being this, that in the case of the jar or coated pane, the intermediate insulator or dielectric is a solid, and the opposed conductors fixed, so that all motion by the resulting attraction is precluded, and all discharge between the conductors effectually prevented. The amount of charge which might be possibly collected on a small surface in this way, under a very dense atmosphere, is quite unknown. The charge might continue to accumulate until the resulting force between the opposed surfaces became so great, as to fracture the most impervious insulating substance placed between them.

39. The two following illustrations are conclusive of the general application of the laws above mentioned to the phenomena observable in accumulating electricity between two conducting surfaces under the conditions above mentioned.

1. Let A B, fig. 8, be two attracting plane areas, one of which is charged, and the

other, B, free; let the force between them with a unit of quantity = 1: suppose these areas to become now twice as great; then we have the charge distributed on twice the surface; and if we conceive it in each instance to be distributed equally, there would in the latter be then only one half the quantity in any given point, and hence, as found by experiment (16.) (18.), the indication of the force by the electrometer would become reduced to one fourth. In this state let the quantity be doubled, we have then by the same law (16.) the attractive force = 1, as before; that is to say, the charge which can be accumulated under a given attraction and distance between the plates, is as the opposed areas directly.

Now the indication of the charge by the electrometer, E, fig. 8, connected with the charged side, are, as we have seen (16.) (15.) (18.), proportional to the square of the quantity of electricity which the free surface ceases to hold in equilibrio. But the amount of charge and distance of the plates being constant, the quantity of electricity held in equilibrio will vary with the areas; and therefore if the area and quantity vary together, the electrometer will not change; hence it is, that a given number of degrees may, under this condition, correspond with any quantitative accumulation whatever.

If, then, we conceive in fig. 8. the two opposed plates to be the coatings of the intervening air, or any other dielectric, then, as just shown, the accumulation under a given intensity will be as the areas opposed.

2. Let the force between the plates A B, fig. 8, at a unit of distance *a b*, and with a unit of quantity = 1 as before, and suppose the distance *a b* to become now twice as great; then the force of attraction will be reduced to one-fourth, since it varies as $\frac{1}{D^2}$. Let the quantity under this condition be doubled, the attractive force will be = 1 as at first, since it is as the square of the quantity (4.); hence the accumulation between the opposed areas is under a constant attractive force directly as the distances between them.

Now the indications of intensity by an electrometer E, fig. 8, in connexion with the charged side, will be, as in the former instance, dependent on the reflected action of the free plate: this, taken in degrees of the electrometer, is as we have just seen (15.), as the squares of the distances inversely. If, therefore, with the quantity one, the distance *a b* be doubled, the intensity by the electrometer will be quadrupled: under this condition, let one half the quantity be again withdrawn, then the intensity by the electrometer will be the same as the first. If, therefore, we suppose, as in the preceding case, that the opposed plates are merely the coatings of the interposed dielectric, it follows that the charge under a given intensity will be as the distance between the plates inversely.

These deductions are in complete accordance with the many experiments made in this department of science by the learned Mr. Cavendish, who states in the 66th vol. of the Royal Society's Transactions, "that the quantity of electricity which coated glass can receive under the same degree of electrification is as the area of the coating directly, and as the thickness of the glass inversely."

It may be further remarked, that the force between two planes *m*, *f*, fig. 1, is not sensibly increased by increasing the area of one of the coatings only; is not influenced by the form or dimensions of the unopposed portions; and is the greatest possible when one of them is placed in a free state: circumstances which apply particularly to the case of charged glass. In considering the attractive force, therefore, between two conducting bodies of any form whatever, one of them being charged, the other free, it is only requisite to take into the calculation the opposed surfaces, and reason upon the inductive actions and distance according to the laws already given (27.) (32.) (34.).

40. Let for example the opposed bodies A, B be two spheres, as in fig. 18, or cones, or paraboloids, as in fig. 19, then the intervening dielectric will be of the form *a c e f b d a*, and the coatings *a d b c e f*, will be hemispherical or otherwise, according to the figures; and the unopposed portions, taking the bodies in a charged and free state, will not affect the result; they may be of any form, or have any connexion whatever with other bodies. We may always predict the attractive force, a unit of force at a unit of distance being given, on the supposition that it is as the opposed areas directly, and as the squares of the distances inversely; the electricity accumulated in the opposed points being as the square roots of the respective distances* (32.).

This general result is not vitiated by any oblique action which may appear to arise in consequence of change in the position of the opposed surfaces. Thus if the two opposed plane areas, *d*, *f*, fig. 20, be any how placed, provided they maintain their relative position with respect to each other, it is evident no difference can possibly arise; it would be in fact merely placing a coated pane in different angular positions. If we suppose one of the plates brought into the position *a b*, fig. 21, so as to be oblique to the other, still the same general principle applies: we may conceive the interval of air, *a n m b*, to be a solid dielectric of unequal thickness, the coatings of which are the opposed areas *a b*, *m n*; the attractive force, therefore, between the plates, *a b*, *a′ b′*, would become diminished by the exposure of the unopposed portions, *n a′*, *m b′*, and by the general increase of distance. If the plates were so opposed as to cause a portion of one to project beyond the other, as in fig. 22, then the force would be reduced to the opposed portions, *a m*, *n d*, and would be diminished by the external unopposed parts *n c*, *m b*.

We suppose, however, in all these cases that the force is exerted between a neutral body in a free state, and a body charged with a quantity of electricity, considered indefinitely great with respect to the opposed surfaces; directly, however, we limit these conditions, either by insulating the neutral body or by narrowing the capacity of the charged body, then corresponding variations arise in the laws of the force, but which may be reduced to calculation on the general principles above stated (37.).

41. The influence of induction on the repulsive force evinced by similarly electrified substances is such as to merit very particular attention; I have shown in the

* Transactions of the Royal Society for 1834, p. 240.

second series of these inquiries, that the operation of electrical repulsion is subject occasionally to considerable variation, the result being dependent on quantity, intensity, distance, and a variety of other contingent circumstances*. Without taking into account, therefore, the attractive forces generated between the discs, *m*, *f*, fig. 11, I could not, by the method of experiment before employed (24.), obtain any uniform result; the repulsive force appeared irregular, and in many cases capricious, appearing sometimes as great at one distance as at another: but in calculating first the force of the disc *f* when charged, on *m* taken as neutral, and then the force of *m* similarly charged, on *f* taken as neutral, the results, with the corrections thus deduced, were uniform, and according to a given law, as may be seen in the following experiment.

Exp. 30. Two discs, *m*, *f*, fig. 11, being opposed to each other, one of them *m*, was charged with a given quantity, and the other placed in connexion with a coated jar, charged with the same electricity; the charges in the latter were estimated by the unit measure. The elementary measurements were, first, the attraction of the suspended disc *m*, charged with a given quantity; on *f*, considered as neutral $= a$; secondly, the attraction of *f*, charged with a given number of measures, on *m*, taken as neutral $= p$; lastly, the repulsive force between the bodies with a given number of measures = R. The attractive forces were neutralized by small weights placed on the scale pan *p*; the arm *g* of the balance, up to the instant of the repulsion, rested on a small support projecting from the brass work supporting the beam B. The repulsive force was estimated by weights either placed on the disc *m*, or otherwise removed from the scale pan, and by which the whole had been previously brought to balance.

The annexed table comprises the numerical results of a few experiments conducted in this way; the attractive force between *m* and *f*, taking *m* charged, varied as the square of the distance inversely, or very nearly, for the quantities employed. The force, taking *f* charged, was in general so small as to admit of being neglected (Exp. 22.).

TABLE VI.

Distance.	Attr. Force.	Rep. Force.	Quantity.
·4	5	9	38
·8	1+	4·5	36
1·2	0·3	3+	36
1·6	..	2+	37

It may be seen here that the repulsive force was in the simple inverse ratio of the distance, and that the number of measures for each experiment did not greatly differ.

A similar result was obtained by means of the electrometer, fig. 1: the attractive forces were here very easily determined, and the number of corresponding degrees

* Transactions of the Royal Society for 1836.

noted, by employing charged glass, as in Experiment 22. The repulsive forces alone were obtained; they were, however, still in the simple inverse ratio of the distances.

42. These phenomena may not be unimportant to further advances in this department of science; they rather lead us to consider electrical attraction as essentially differing in its nature from forces emanating from a centre, and go far to assist us in elucidating many of its operations, hitherto considered of a complicated character. Thus the attractive force between spheres and bodies of other forms has given rise to a mathematical analysis of some difficulty*, which although displaying the highest order of talent is certainly not indispensable. We may on very simple principles determine, as already shown (40.), the laws of the force between bodies of any form, whether insulated or free, whether charged positively or negatively, or whether electrics or conductors.

43. The following are a few simple expressions which may be taken to represent some of the elementary laws of electrical induction and attraction, in which $Q =$ quantity of charge, T the direct induction, q the quantity of electricity displaced, t its intensity, T' the reflected induction, q' the disturbed quantity, t' its intensity, q'' the total quantity in the opposed charged surface, A the surface, D the distance between the opposed points, $F =$ force of attraction.

We have then for the direct induction

$$T = q = \frac{Q}{\sqrt{D}}, \qquad t = \frac{Q^2}{D}.$$

For the reflected induction T' we have

$$T' = q' = \frac{Q}{D}, \qquad t' = \frac{Q^2}{D^2}, \qquad q'' = \frac{Q}{\sqrt{D}}.$$

We have for the attractive force between a charged and neutral free conductor

$$F = \frac{Q^2}{D^2}, \qquad F = \frac{T}{A^2}.$$

For the force between an unchangeable positive and negative surface we have

$$F = \frac{Q^2}{D}.$$

44. In these inquiries I have not resorted to the view of electrical action I was led to entertain in the first series of these papers, in which a portion only of the whole charge is supposed to be appreciable by the electrometer, being unwilling to embarrass the inquiry with theoretical speculations not essential to a full development of the experimental facts. I may, however, still observe, that the present state of this department of science does not warrant any very perfect confidence in the common mechanical explanations of the mode of operation of electrical forces generally, and which after all seems to be of a cumbrous and difficult character. If we suppose a particle of the electricity $= a$ on a charged body A, fig. 8, to attract every par-

* Supplement Encyclop. Britt., Article ELECTRICITY.

ticle of the opposite electricity = *b* on the opposed body B, instead of supposing the force to be confined to the near particle immediately opposed to it, we cannot take all the forces as equal, and the whole force to be as *a b*; it must still be only as some function of it, and we have to sum the forces under this condition. But in this case even, all the oblique actions may at last be indefinitely small in respect of the force exerted upon the opposite and nearest particle, which would still admit of the whole action being reduced to a system of parallel forces, such as represented in fig. 18, more especially when we take into consideration the fact that the force between two particles, *a*, *b*, fig. 23, is greatly diminished, and may become very small by placing a similar third particle, *d*, nearer either of them, supposing it charged with the opposite electricity; and this result will be again augmented by placing another particle, *e*, nearer the other in a similar way. In this case the action between the original particles *a*, *b* almost vanishes.

45. In concluding this communication it may not be improper to state, that the experiments were conducted in a good insulating atmosphere, generally in a room dried by an air stove: the late contrivance of Dr. ARNOTT is quite invaluable to the practical electrician for this purpose. The manipulations requiring especial care are, 1. Measure of quantity; 2. of distance; 3. Adjustment of the electrometer, especially in such experiments as No. 26; 4. Perfection of the insulators. The circumstances liable to interfere with a rigid numerical result are, slight changes in the position of the bodies under experiment,—the bodies should be firmly steadied; inaccuracy in the value of the unit measures, either by less perfect insulation of the air, or by other causes; a want of free connexion of the external coating of the jar, P, fig. 16, with the ground; small residuary charges in the discs of the electrometer; these should be always discharged by a bent wire at each experiment. A series of delicate manipulations of this kind, although apparently difficult, may yet by a little habit and attention be completely managed.

Plymouth,
April 10, 1839.

XV. *On the Conditions of Equilibrium of an Incompressible Fluid, the Particles of which are acted upon by Accelerating Forces.* By JAMES IVORY, *K.H. M.A. F.R.S. L. & E., Instit. Reg. Sc. Paris, Corresp. et Reg. Sc. Gottin. Corresp.*

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EXPERIENCE shows that physical problems of difficulty are never solved in a satisfactory manner but after reiterated attempts. The examples that might be adduced in support of this remark, are too obvious and numerous to need particular mention. A remarkable instance is the problem of which it is proposed to treat in this paper, namely, that relating to the figure of equilibrium of a mass of fluid, the particles of which are subjected to the action of accelerating forces. This problem, suggested by the inquiry into the figure of the planets, was first treated of by NEWTON and HUYGHENS; it then passed into the hands of MACLAURIN, CLAIRAUT, and D'ALEMBERT; and it finally occupied the attention of EULER, LAGRANGE, and LAPLACE, by whose researches it is declared on high authority* that the solution is completed, leaving no difficulties, except of a mathematical kind, in applying it to any case that may be proposed. The theory thus finally settled is imposing by its great generality and apparent simplicity; it succeeds in solving a certain class of problems, although not on sound principles; but in other instances no degree of mathematical skill has been able to obtain satisfactory results. A candid inquirer who will endeavour to form just notions of the conditions required for the equilibrium of a fluid, will not fail to have his attention arrested by much that is inconsistent and obscure in the usual manner in which this subject is treated. This seems to imply some imperfection in the grounds of the theory; and the best way of removing all difficulties is to mount up to the origin of the inquiry, and to trace it with careful examination through all its successive steps. In this manner we may detect what is defective or erroneous; and having arrived at physical conditions not liable to objection or uncertainty, the theory may be placed on a firm foundation.

It will not be necessary to say a word on the importance of a theory which has occupied the attention of so many eminent geometers, and which is the subject of no small part of what has been written on the system of the universe. As it treats of the figure of a fluid, it seems to suppose that the earth and planets were originally in a state of fluidity, either by the solution of their solid parts in a liquid, or by the effect of heat. Now as we have no knowledge of the primitive condition of the bodies of our system, it may be objected that the problem, whatever ingenuity may be re-

* M. POISSON.

quired to overcome its difficulties, is merely speculative and hypothetical. But the matter may be viewed in a different light. No small progress has already been made in the investigation of the figure of the earth; and our knowledge in this respect may be made more perfect by assiduous observation and discussion: we are also acquainted with all the forces, whether attractive or centrifugal, that urge every particle of the matter of which our globe is composed; and hence, reversing the usual question, the inquiry may be, whether a change in the actual figure of the earth would necessarily take place if the bonds that hold together its solid parts were loosened, and a state of fluidity induced upon the whole or any portion. A speculation of this kind at any time, and in every revolution imposed by fashion on scientific research, may be deemed not altogether uninteresting, and may be useful in studying the changes that take place on the surface of our globe.

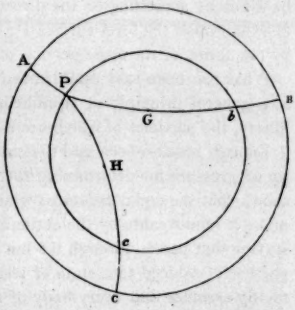
1. It is obvious that a homogeneous body of fluid, the particles of which are not agitated by extraneous forces, but are left freely to their mutual action on one another, will ultimately assume the figure of a perfect sphere. In treating of the figure of the earth, Newton supposes that this sphere is made to revolve about one of its diameters; in consequence of which the centrifugal force will cause the fluid to recede from the axis of rotation, and to subside in the direction parallel to that axis. He makes no inquiry into the nature of this new figure, but immediately concludes, without assigning a reason, that it is an oblate elliptical spheroid turning about the less axis.

It would be in vain to inquire on what grounds Newton inferred that the revolving sphere is changed into an exact oblate spheroid. The flattening at the poles suggests a resemblance of the two figures; and we may add that, by making the two axes of the spheroid more and more unequal, it will pass through all degrees of oblateness, and may be supposed, in some one of its forms, to coincide with the flattened sphere, if not exactly, at least with a sufficient approximation.

Having guessed the form of equilibrium, the main difficulties of the research were overcome; for it is much easier to investigate the properties of a known figure, than to determine the form itself which is required for an equilibrium. He begins with laying down this principle, that in a fluid spheroid in equilibrium, the weights, or efforts, of all the small rectilineal columns extending from the centre to the surface, must balance one another round the centre. Assuming a spheroid, of which the axes are very nearly equal, namely, 101 and 100, he computes, by means of his assumed principle, and some propositions in his immortal work, the weights at the centre, caused by the attraction of the matter of the spheroid, of two columns, one drawn in the plane of the equator, and the other to the pole. The spheroid must next be supposed to revolve about the polar axis, so that the centrifugal force, by diminishing the weight of the equatorial column, may equalise the weights of both columns at the centre, as an equilibrium requires; and when this condition is fulfilled, it is found that the oblateness of the spheroid, or the difference of the two semi-axes in parts of

the equatorial radius, is to the centrifugal force at the equator in parts of the gravity, as 5 to 4. Now this proportion of 5 to 4 is common to all spheroids of which the axes are nearly equal; and as the centrifugal force at the earth's equator is $\frac{1}{289}$ of gravity, the oblateness of the terrestrial spheroid will be $\frac{5}{4} \times \frac{1}{289} = \frac{1}{230}$, making the proportion of the polar axis to the diameter of the equator as 229 to 230. Such would be the true figure of the earth if its matter were homogeneous, and if NEWTON's reasoning were liable to no objections. All that the present purpose requires to be noticed in his very able investigation, is the principle of the equiponderance of the central columns which he introduced.

NEWTON had occasion to consider no figure but the elliptical spheroid, in which, from its symmetry, the equiponderance of the central columns is self-evident, every column being counteracted by an equal and similar column diametrically opposite. In a body of fluid at liberty and in equilibrium by the action of accelerating forces, is there always a central point round which the efforts of the whole mass balance one another? It is obvious that all canals extending from a particle to the surface of the fluid, will impel the particle with equal intensity; for otherwise the particle would not be at rest. What is it, then, that distinguishes the equal pressures upon a particle in any situation, from the like pressures on the central point, if there be such a point? In a research in which there have occurred so many inadvertencies arising from hypothetical admissions, it is necessary to inquire in what manner the pressures are distributed among the particles.



Let A B C represent a mass of fluid in equilibrium; P any particle; P A, P B, P C, small canals diverging to the surface of the fluid: as P is at rest, the efforts of all the canals will balance one another. In passing along any canal A P B ending both ways in the surface, the pressure, which is zero at A, will first increase to a certain point G, after which it will decrease to zero at B. Because the pressure from A to G is equal and contrary to the pressure from B to G, there is always a part B *b* at one end, which presses inward with an intensity equal to the like effort of the part A P at the other end. Thus, of the three parts of the canal, the forces which urge the fluid in the two extreme parts transmit equal and contrary pressures to P; but the forces acting on the fluid in the middle part P *b*, destroy one another's effects, and cause no pressure on P. The same thing is true of any other canal A P C; the effort of the part A P on one side of the point of maximum-pressure H being balanced by the

contrary effort of the part C *c* on the other side of that point. Now if we suppose a curve surface to be drawn through P, and through all the points *b*, *c*, &c., it follows from what has been proved, that the pressures which impel P with equal intensity in all directions, are caused solely by the forces which urge the portion of fluid on the outside of that surface; for any canal being drawn between P and the upper surface, it is only the part of such canal between the two surfaces that transmits an effective pressure to P.

Such interior surfaces as P *b c* are called level surfaces. Every level surface is pressed at all its points with the same intensity by the exterior fluid; for the forces acting on the particles contained in any canal between a level surface and the upper surface, produce the same effort directed inward.

If we conceive that the interior surface P *b c* gradually lessens in its dimensions by the increasing depth, it will finally contract into a point; which point, or centre, is distinguished from every other point P, by this, that the pressures which impel it equally in all directions are produced by the forces which urge all the particles of the body of fluid.

The central point is distinguished by another property peculiar to it: for the pressure being a maximum, the partial differentials of the pressure, or the forces, will be zero: so that if a particle in the centre be removed a little in any direction, there will be no sensible change of the pressure upon it. Thus the centre is in stable equilibrium with respect to the action of the whole mass of fluid. Although any other particle, as P, is pressed equally on all sides, yet, as the forces in action are not zero, the change of pressure which it undergoes when moved a little from its place, will be different according to the direction of its motion; unless it be moved so as to continue upon the level surface P *b c*, in which case the pressure, being still produced by the action of the same portion of the whole mass, will not vary.

What has been said establishes Newton's equiponderance of the central columns as a general principle of equilibrium that holds in every case of a mass of fluid at liberty, the particles of which are urged by accelerating forces.

Enough has also been said to demonstrate the insufficiency of the principle of equality of pressure for determining the figure of equilibrium of a fluid. For it has been shown that the equal pressures which a particle sustains have no other effect than to make it immoveable by the action of the portion of fluid on the outside of the level surface that passes through it: but from this it does not follow in all cases that the particle is reduced to a state of rest relatively to the whole mass. The same theory tacitly assumes that every body of fluid contained within a level surface will maintain its form and position, merely by the equal pressures of the exterior fluid; not adverting to the necessity of taking into account all the forces of whatever description that act on the particles. In the foregoing investigation it is clearly proved on the supposition of an equilibrium, that the forces in action must be without effect to cause pressure either way in any canal, as P *b* or P *c*, within a level surface.

2. Some years before the publication of the Principia, it had been ascertained by observation that the same mass of matter has not the same weight at all the points of the earth's surface. A pendulum clock regulated by mean time at Paris was found by M. RICHER to lose two minutes a day at Cayenne, within 5° of the equator. Now the length of a pendulum that oscillates in a given time is an exact measure of gravity; and the fact observed by M. RICHER proved that, if a heavy body were carried from Paris to Cayenne, it would lose some part of its weight. On learning this fact, HUYGHENS conjectured that it was caused by the centrifugal force arising from the daily revolution of the earth; the intensity of this force varying in different latitudes at different distances from the axis of rotation. Combining this observed variation of gravity with a principle, which is indisputably true, namely, that a plumb-line freely suspended is perpendicular to the surface of standing water, or to the surface of the earth supposed entirely fluid, he drew an argument, that the earth is not exactly spherical. Were the earth a perfect sphere, the attraction of its mass would be perpendicular to the surface at every point: the centrifugal force, directed at right angles from the axis of rotation, is oblique to the surface: wherefore gravity, being the resultant of both forces, and consequently not coinciding in its direction with either, would not be perpendicular to the surface, which is contrary to the admitted principle. It will readily appear that the resultant of the two forces, or the true direction of the plumb-line, would always make a small angle with the radius of the sphere on the side towards the equator: so that a horizontal plane perpendicular to this direction, would necessarily fall within the sphere towards the pole: which is a direct proof that the surface of the earth, formed by all such horizontal planes, is depressed at the poles. These speculations of HUYGHENS are contained in his dissertation, *De causa gravitatis*: in an addition to that dissertation which was published after the author's death, he proceeds to investigate the oblateness of the earth, or the difference between the equatorial radius and the polar semiaxes, caused by the centrifugal force. By this time the Principia was published: but the doctrine of the mutual gravitation of all matter, was at first generally objected to, and forced its way very slowly to universal approbation. HUYGHENS, rejecting the principle that every particle of matter gravitates to every other, substituted in its place a tendency of all the parts of the earth supposed in a fluid state, to the common centre of the mass, the central force acting with the same intensity at all distances. Following the method devised by NEWTON for the solution of the same problem, the simple law of gravity adopted by HUYGHENS leads to an easy solution: because a narrow rectilineal canal of any length drawn from the centre, will have a weight proportional to the quantity of fluid it contains. If a fluid spheroid revolve about the polar axis with a circular velocity capable of impressing on the particles a centrifugal force the intensity of which is to that of gravity as n to 1, it is easy to prove that the centrifugal force will diminish the weight of a canal in the plane of the equator, and equal to the radius of that circle, or to 1, by the quantity $\frac{n}{2} \times 1$: so that the whole weight

of the canal from being equal to 1 will be reduced to $1 - \frac{n}{2}$; which will therefore be the length of a canal reaching from the centre to the pole equiponderant to the equatorial canal. Applying this result to the earth, we have $n = \frac{1}{289}$, and the proportion of the radius of the equator to the polar semi-axis equal to 578 to 577, the oblateness being much less than in the Newtonian Theory.

HUYGHENS next attempts to investigate, what form the perpendicularity of gravity to the earth's surface requires the terrestrial meridians to have. But in this part of his researches no result is obtained which it would be useful to notice. He finds indeed a curve which, in his law of gravity, answers the mathematical conditions: but this curve is a paraboloid consisting of two infinite branches that diverge continually from one another; a form irreconcilable with the continuous surface of the earth, every meridian of which is an oval curve returning into itself. It appears from what has been said that the contribution of HUYGHENS to the theory of the equilibrium of fluids, must be limited to the perpendicularity of the resultant of the forces to the surface, which principle he was the first to suggest.

3. We have now two properties that must be verified in every mass of fluid at liberty and in equilibrium by forces acting on its particles, namely, the equiponderance of the central columns of which NEWTON is the author, and the perpendicularity to the surface of the resultant of all the forces urging a particle, which was proposed by HUYGHENS. But it is one thing to detect particular properties of an equilibrium, however general in their application, and another thing to fix with precision the conditions necessary for inducing that state on a mass of fluid acted upon by given forces. In solving problems, geometers sometimes made use of one principle, and sometimes of the other. It was soon found that a figure obtained by means of one principle, did not in all cases verify the other; and even that the concurrence of both in the same mass of fluid was not sufficient in some instances to ensure an equilibrium. From all this it could only be inferred that the problem was still involved in obscurity, and required to be further discussed.

4. In the Principia NEWTON has completely determined the attraction of spheres. He has also given methods for determining the attraction of other bodies; which methods, although sufficient for obtaining numerical results, fail for the most part in ascertaining the law according to which the attractive force of the mass will vary when the attracted point changes its place. MACLAURIN, by a happy application of the ancient geometry, determined this law in elliptical spheroids of revolution, for all particles within the solid or in its surface. He found that the mass of the spheroid attracted a particle so situated, in directions perpendicular to the plane of the equator and to the axis of rotation, with forces respectively proportional to the distances from the plane and from the axis*. Now the centrifugal force is directly proportional to

* Although MACLAURIN's demonstration rests on this property, yet this property itself is essentially dependent on another property, which the author has demonstrated in his Fluxions, § 630.

the distance from the axis of rotation: and thus was known every force tending to move any particle of an elliptical spheroid revolving about its axis in a given time. The difficulty of estimating the forces and pressures in different parts of the spheroid, obliged NEWTON to confine his attention to the central columns. The discovery of MACLAURIN removed this difficulty, and enabled him to ascertain whether the spheroid fulfilled any proposed property of equilibrium, or not. He first determines the relative dimensions of the spheroid, which are necessary for making the resultant of the attractive and centrifugal forces perpendicular to the surface at every point, as is required by the principle of HUYGHENS; and he demonstrates that the same figure verifies NEWTON'S principle of the equiponderance of the central columns. Taking now any particle, or small portion of the fluid, and conceiving that it is pressed on every side by rectilineal canals standing upon it and terminating in the surface, he showed that the pressures of these canals impel the particle equally in all directions. These several points are demonstrated with the utmost elegance, and with all the rigour of EUCLID or ARCHIMEDES.

Such is the celebrated demonstration of MACLAURIN, which adds the property of every particle being pressed equally in all directions, to what NEWTON and HUYGHENS had before shown to be necessary for an equilibrium. But on reflection it is not quite clear how this new property is to be understood or what use is to be made of it. There is no doubt that most authors infer, from the equal pressures which a particle sustains on every side, that it it is necessarily brought to a state of rest within the spheroid; and hence the equality of pressure has been erected into a general principle, on which is founded the usual theory of equilibrium. But what MACLAURIN does really demonstrate amounts to this*, that a particle placed on an elliptical surface similar and concentric to the surface of the spheroid, is impelled by any rectilineal canal standing upon it and terminating in the surface of the spheroid, with a pressure equal to the effort of a given canal having for its length the difference of the polar semi-axes of the two similar surfaces. Now the proper inference certainly is, that the particles at every point of the interior surface press upon one another, and upon the surface in which they are placed, with the same intensity. To say that a particle is pressed equally in all directions, is tantamount to saying that it is placed on a level surface; every particle on such a surface being urged equally on all sides by the exterior fluid, either by direct action, or by the efforts transmitted through the fluid contained within the surface. But it cannot be reasonably inferred, as is done in the theory of equilibrium founded on equality of pressure, that a particle is reduced to a state of rest relatively to the whole of a body of fluid, merely because it is pressed equally in all directions by a portion only of the mass.

In the treatise on Fluxions published in 1742 MACLAURIN does not affirm explicitly that a particle is at rest within the spheroid, because it is pressed equally on all sides; although it is undoubtedly implied that this is true: and he concludes his investiga-

* Fluxions, § 639.

tion* with saying, that the surfaces similar and concentric to the surface of the spheroid, are the true level surfaces at all depths; which is alone sufficient for the equilibrium, and is indeed the simple and direct and the only exact ground of the demonstration, agreeing perfectly with what has been advanced. In the Dissertation presented by the author to the Academy of Sciences in 1740, the matter is differently stated. Having proved, in his first proposition or *Theorema Fundamentale*, that any particle is impelled equally in all directions by a certain force depending only on the position of the particle, or rather on the surface passing through the particle similar and concentric to the surface of the spheroid, he adds, "*quæ* (*particula*) *cum æqualiter urgeatur, fluidum est ubique in equilibrio.*" Here it is unequivocally asserted that the equal pressures which a particle sustains, reduce it to a state of rest within the spheroid. This would be correct if it were proved that the equal pressures are produced by the action of the whole mass of the spheroid. That a particle is pressed equally by the surrounding fluid, and that it is at rest within the spheroid, are two distinct propositions, of which the second is not necessarily a consequence of the first: for the equal pressures may be caused by the action of only a part of the fluid; whereas the effect of the forces that act upon all the particles must be taken into account, in order to prove that a particle is at rest relatively to the whole mass. What Maclaurin has accurately proved of one particle, holds equally of all the particles situated in any surface similar and concentric to the surface of the spheroid, the pressure on all such particles being the same; and the proper inference to be drawn is what the author has stated in his Fluxions, namely, that all such interior surfaces are the true level surfaces at all depths.

5. In proving that the pressure upon any interior particle of the spheroid is equal in all directions, Maclaurin used rectilineal canals; but it is evident that the effect must be the same, whether the canals be rectilineal, or have curvilineal figures varied in any manner. From observing that, in a fluid at rest, the pressure of a canal will be the same when its extreme points are the same, however its form may be varied, Clairaut deduced a relation between the figure of a fluid in equilibrium and the mathematical expression of the pressure, or of the forces which produce the pressure. This consideration greatly simplified and improved the theory of equilibrium, as it made it unnecessary to seek after such artifices of investigation as Maclaurin was obliged to have recourse to. This property is enunciated in the following theorem.

Theorem.—In a fluid at rest by the action of accelerating forces on its particles, the mathematical expression of the pressure at any point of the mass can be no other than a function of the three co-ordinates of the point, these co-ordinates being considered as independent and unrelated quantities.

Demonstration.—Let a communication be opened between any two points of the mass of fluid by means of a canal of any figure; because the fluid is supposed to be

* Fluxions, § 640.

at rest, the pressure of the fluid in the whole length of the canal will be equal to the difference of the pressures in the body of fluid at the two orifices, which pressure will therefore remain the same, however the figure of the canal be varied. It is easy to ascertain that this property will be verified when the pressure at any point of the fluid is represented by a function of the co-ordinates, such as is described in the theorem. Thus the co-ordinates of the two orifices of the canal being represented by a, b, c and a', b', c'; and the pressures at the same points by $\varphi(a, b, c)$ and $\varphi(a', b', c')$; through whatever gradations the figure of a canal requires that the independent variables a, b, c be made to pass so as finally to become equal to a', b', c', the function $\varphi(a, b, c)$ will always be changed into $\varphi(a', b', c')$.

But the theorem may be regularly demonstrated in the manner following. Let the variables x, y, z represent the co-ordinates, and $\phi(x, y, z)$ or ϕ the pressure at a point of the fluid: if the co-ordinates vary in the curve of the canal, the sum of the differentials in the whole length of the canal will be

$$\int\left(\frac{d\phi}{dx}dx + \frac{d\phi}{dy}dy + \frac{d\phi}{dz}dz\right);$$

and the sum of the variations of all these differentials in another canal very near the first and between the same extreme points, will be

$$\int\delta.\left(\frac{d\phi}{dx}dx + \frac{d\phi}{dy}dy + \frac{d\phi}{dz}dz\right);$$

and the condition that the pressure caused by the efforts of the fluid in one canal is not different from the like pressure in the other canal, is thus expressed:

$$0 = \int\delta.\left(\frac{d\phi}{dx}dx + \frac{d\phi}{dy}dy + \frac{d\phi}{dz}dz\right).$$

When this last expression is integrated by parts, we obtain

$$\begin{aligned} 0 = {} & \frac{d\phi}{dx}\delta x + \int dx\,\delta.\frac{d\phi}{dx} - \int\delta x\,d.\frac{d\phi}{dx} \\ & + \frac{d\phi}{dy}\delta y + \int dy\,\delta.\frac{d\phi}{dy} - \int\delta y\,d.\frac{d\phi}{dy} \\ & + \frac{d\phi}{dz}\delta z + \int dz\,\delta.\frac{d\phi}{dz} - \int\delta z\,d.\frac{d\phi}{dz}. \end{aligned}$$

Now the terms without the sign of integration in this expression are zero when the integrals are extended to the whole lengths of the canals; for the extreme points being fixed, the variations of the co-ordinates at these points are zero. We thus obtain by an easy reduction,

$$\begin{aligned} 0 = {} & \int(dx\,\delta y - \delta x\,dy)\cdot\frac{dd\phi}{dx\,dy} + \int(dx\,\delta z - \delta x\,dz)\cdot\frac{dd\phi}{dx\,dz} \\ & + \int(dy\,\delta x - \delta y\,dx)\cdot\frac{dd\phi}{dy\,dx} + \int(dy\,\delta z - \delta y\,dz)\cdot\frac{dd\phi}{dy\,dz} \end{aligned}$$

$$+\int (dz\,\delta x - \delta z\,dx)\cdot\frac{dd\phi}{dz\,dx} + \int (dz\,\delta y - \delta z\,dy)\cdot\frac{dd\phi}{dz\,dy}:$$

which equation will be verified only by means of these formulas, viz.

$$\frac{dd\phi}{dx\,dy} = \frac{dd\phi}{dy\,dx},\quad \frac{dd\phi}{dx\,dz} = \frac{dd\phi}{dz\,dx},\quad \frac{dd\phi}{dy\,dz} = \frac{dd\phi}{dz\,dy}.$$

Now these equations express the well-known conditions that the variables of the function $\phi\,(x, y, z)$ are independent quantities; which sort of function is therefore alone fit to represent with consistency the pressure of a fluid at rest.

The nature of the pressure in a fluid at rest being ascertained, the expressions of the forces which produce the pressure follow as a corollary; for these expressions are necessarily no other than the partial differentials of the pressure. Supposing always, for the sake of simplicity, that the density is constant and equal to unit, let X, Y, Z represent the forces which, acting in the respective directions of the co-ordinates, produce the pressure $\phi\,(x, y, z)$ or ϕ; we shall have

$$X = \frac{d\phi}{dx},\quad Y = \frac{d\phi}{dy},\quad Z = \frac{d\phi}{dz}.$$

From the foregoing equations between the differentials of ϕ, the following formulas are easily deduced, viz.

$$\frac{dX}{dy} = \frac{dY}{dx},\quad \frac{dX}{dz} = \frac{dZ}{dx},\quad \frac{dY}{dz} = \frac{dZ}{dy}.$$

These equations are the known conditions for the integrability of the differential

$$X\,dx + Y\,dy + Z\,dz:$$

and they must be verified in every problem by the proposed forces, otherwise the equilibrium of the fluid will be impossible.

If p represent the pressure estimated on a given surface at the point $(x\,y\,z)$ of the fluid, we shall have,

$$p = \phi\,(x, y, z), \quad \text{(A.)}$$

$$p = \int (X\,dx + Y\,dy + Z\,dz),$$

the integral extending from the point to the surface of the mass. We next obtain these differential equations,

$$dp = \frac{d\phi}{dx}\,dx + \frac{d\phi}{dy}\,dy + \frac{d\phi}{dz}\,dz,$$

$$dp = X\,dx + Y\,dy + Z\,dz:$$

and if we suppose $dp = 0$, or that the co-ordinates vary in a surface at every point of which the pressure is the same, that is, in a level surface, the surface of the mass being included, there will result

$$0 = \frac{d\phi}{dx}\,dx + \frac{d\phi}{dy}\,dy + \frac{d\phi}{dz}\,dz,$$

$$0 = X\,dx + Y\,dy + Z\,dz.$$

Now these last equations prove that the forces urging a particle in any level surface have no effect to move the particle in any direction upon a plane touching the surface; from which it follows that the resultant of such forces is perpendicular to the surface in which they act. It is also obvious that the resultant is always directed towards a level surface and towards the surface of the mass.

The equations that have been investigated are common to every mass of fluid at liberty and in equilibrium by the action of accelerating forces on its particles. The same equations contain all that is taught in the usual manner of treating this subject. If we suppose that the pressure p remains constant, while the co-ordinates vary, the equation (A.) will determine a level surface. If the point at which the pressure is p remains fixed, while the co-ordinates vary in any canal terminating in the surface of the fluid, the same equation (A.) proves that all the canals will exert the same pressure p upon the point. Every point in a level surface is impelled in all directions with the same intensity of pressure; and nothing is gained, but the hazard of misconception is incurred, by applying equality of pressure to isolated points.

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MACLAURIN's demonstration will always be admired; but that geometer was unfortunate in considering the pressure upon an isolated point. If he had observed, what follows from his reasoning, that every particle in a surface similar and concentric to the surface of the spheroid is pressed equally on all sides, he would have been led to the property of the level surfaces of which he has ultimately made use in his Fluxions, and which is the true principle of the equilibrium of a fluid, namely, that the level surfaces at all depths must have determinate figures.

Although the equation (A.) is common to every fluid in equilibrium, it does not follow that every problem can be solved by one equation. The level surfaces depend upon the proposed forces; and they require for the determination of their figure as many independent equations as these given forces that derive their origin from independent sources.

The not observing that in every canal terminating both ways in the surface of the fluid there are always two points pressed inwards in contrary directions with the same intensity, and consequently an intermediate part which presses neither way, has occasioned the misconception, from which much confusion has arisen, that the equal pressures of the surrounding fluid upon a particle necessarily reduce it to a state of rest within a body of fluid in equilibrium.

6. The following Problems are added for elucidating the principles that have been investigated.

PROBLEM I.

To determine the figure of equilibrium of an incompressible fluid when the forces are such functions of the co-ordinates as are susceptible of only one value for any proposed values of the co-ordinates.

Solution.—Let x, y, z denote the co-ordinates of a particle of the fluid, p the

pressure, and X, Y, Z the forces acting in the respective directions of x, y, z; from the equation (A.) we obtain

$$p = \int (\mathrm{X}\, d\, x + \mathrm{Y}\, d\, y + \mathrm{Z}\, d\, z);$$

or, as the integration may always be effected, if $\varphi\,(x, y, z)$ represent the integral

$$p = \varphi\,(x, y, z).$$

When p is made constant, this equation will determine a level surface, which, in the simple hypothesis of this problem, is a curve susceptible of only one form for every value assigned to p. Now if p passes through all gradations from its maximum value at the centre of the mass to zero at the upper surface, all the level surfaces will be ascertained; this determines the form of the mass; and the equilibrium follows from the consideration that the level surfaces at all depths are determinate curves.

Of this problem an example is added, which is not undeserving of notice on its own account.

Example.—To determine the figure of equilibrium of an incompressible fluid at liberty, the particles being supposed to attract one another with a force proportional to the distance, at the same time that they are urged by a centrifugal force caused by revolving about an axis.

Solution.—On account of the mutual attraction of the particles it may at first be surmised, that the problem here proposed does not come under the head of which it is given as an example. It does not immediately appear that the forces urging a particle depend entirely on the place of the particle, and are explicit functions of its co-ordinates. Such, however, is the case, owing to a property peculiar to the supposed law of attraction, which Newton has demonstrated in the 88th proposition of the first book of his Principia. The property alluded to consists in this, that the resultant of the accumulated attractions of the mass upon a particle is directed to the centre of gravity of the mass, and is the same as it would be if the whole attracting matter were collected in that point. Of this a succinct investigation is as follows.

The origin of the co-ordinates being at the centre of gravity of the whole body of fluid, let x, y, z denote the co-ordinates of an attracted particle, and x', y', z' those of $d\,m$, an element of the mass; the attraction of $d\,m$ upon the particle at the distance f will be $f\,d\,m$; and as the cosines of the angles which f makes with x, y, z are

$$\frac{x - x'}{f},\ \frac{y - y'}{f},\ \frac{z - z'}{f},$$

the partial attractions of $d\,m$ in the directions in which x, y, z decrease, will be

$$d\,m\,(x - x'),\quad d\,m\,(y - y'),\quad d\,m\,(z - z');$$

and by summing the attractions of all the elements, the partial attractions of the whole mass in the same directions will be

$$x \int d\,m - \int x'\, d\,m,\quad y \int d\,m - \int y'\, d\,m,\quad z \int d\,m - \int z'\, d\,m.$$

But by the property of the centre of gravity,

$$\int x' \, dm = 0, \int y' \, dm = 0, \int z' \, dm = 0;$$

wherefore the attractions of the whole mass upon the particle in the same directions as before, will be

$$x \times m, \quad y \times m, \quad z \times m.$$

Now the resultant of these forces is directed to the origin of the co-ordinates, and is equal to $\sqrt{x^2 + y^2 + z^2} \times m$, which is NEWTON's proposition.

Having proved that the example comes under the foregoing problem, it is next to be observed, that the axis of rotation, supposed parallel to x, will pass through the centre of gravity of the mass: for that point must be at rest by the action of all the forces. Assuming $m \times 1$ to represent the central force, and $\varepsilon \times m \times 1$ to denote the centrifugal force at the distance 1 from the axis of rotation; according to what has been shown, the central forces on a particle will be

$$m \times x, \quad m \times y, \quad m \times z;$$

and the centrifugal forces

$$\varepsilon \times m \times y, \quad \varepsilon \times m \times z;$$

wherefore, by equation (A.),

$$X = m \times x, \quad Y = m \times (1 - \varepsilon) y, \quad Z = m \times (1 - \varepsilon) z,$$
$$\text{Const.} = x^2 + (1 - \varepsilon) \, . \, (y^2 + z^2);$$

so that all the level surfaces are elliptical curves; and the figure of equilibrium of the fluid is an oblate spheroid.

The radius of the equator is to the polar semi-axis as 1 to $\sqrt{1 - \varepsilon}$; and if $\varepsilon = \frac{1}{289}$, as in the case of the earth, the proportion is 578 to 577, agreeing with what HUYGHENS found.

PROBLEM II.

To determine the figure of equilibrium of a homogeneous fluid at liberty, the particles attracting one another in the inverse proportion of the square of the distance, at the same time that they are urged by a centrifugal force caused by revolving about an axis.

Solution.—If we adopt for the unit of mass a sphere of the given fluid having its radius equal to a, the attractive force at the surface of the sphere will be $g \times a$, the value of g being the same for all spheres of the same matter; and if the time of one entire revolution about the axis of rotation be denoted by T, the centrifugal force at the surface of the sphere will be $\frac{4\pi^2}{T^2} \times a$; so that the known quantity

$$\varepsilon = \frac{4\pi^2}{T^2} \cdot \frac{1}{g}$$

will denote the centrifugal force estimated in parts of the attractive force.

The origin of the co-ordinates being at the central point, or point of maximum-pressure, let x, y, z represent the co-ordinates of a particle of the fluid, x being parallel to the axis of rotation; and put P, Q, R for the attractions of the whole mass upon the particle in the respective directions of x, y, z: the centrifugal force is equal to $\varepsilon \times \sqrt{y^2 + z^2}$ at the distance $\sqrt{y^2 + z^2}$ from the axis of rotation; and the partial forces parallel to y and z, are therefore $\varepsilon \times y$ and $\varepsilon \times z$: wherefore, taking the total forces acting in the respective directions of x, y, z, we shall have, according to the equation (A.),

$$X = P, \quad Y = Q + \varepsilon y, \quad Z = R + \varepsilon z,$$

$$p = \int (P\,dx + Q\,dy + R\,dz) + \frac{\varepsilon}{2}(y^2 + z^2), \quad . \quad . \quad . \quad . \quad (M.)$$

which equation must be verified by every level surface the upper surface included; p being constant in every level surface, and equal to zero in the upper surface.

Now the equation just found is not sufficient to solve the problem: first, because all the forces that act upon the particles in a level surface, and tend to change its figure, are not taken into account; secondly, because the equation is indeterminate, and incapable of ascertaining a level surface which admits of only one form.

In regard to the first point it is to be observed, that the pressure upon a level surface is the effect of all the forces that urge the particles of the exterior fluid; and in the present instance a part of these forces is the attraction of the fluid within the level surface. But, as action is always attended with reaction, if the fluid within the level surface attract the fluid on the outside and cause it to press, the fluid on the outside will react, and, by its attraction, urge the particles within the level surface to move from their places. It is not necessary to investigate in what manner all the particles within a level surface are acted upon by the exterior fluid: it is sufficient to consider the forces acting upon the particles in the surface itself; because the form of equilibrium of the mass will be ascertained, when the figure of every level surface is determined. Now the nature of a level surface consists in this, that the resultant of all independent forces urging a particle in it, must be perpendicular to it. Wherefore if, as before, x, y, z represent the co-ordinates of a particle in a level surface; and if P', Q', R' denote the partial attractions parallel to x, y, z, of the stratum of fluid exterior to the level surface, we must have this equation,

$$P'\,dx + Q'\,dy + R'\,dz = 0,$$

which expresses the condition that the resultant of the attractions upon the particle is perpendicular to the surface; and in order that the same thing may be true of every point in the surface, we must have the equation

$$\text{const.} = \int (P'\,dx + Q'\,dy + R'\,dz) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (N.)$$

The problem is completely solved by the two equations (M.) and (N.). These equations together take into account all the forces tending to move a particle in a level

surface; and what is wanting in the equation (M.) for giving a determinate figure to any such surface, is supplied by the equation (N.).

If we apply the foregoing solution to the oblate elliptical spheroid, it will immediately appear, according to what is proved in the Principia, Lib. 1. Prop. 91. Cor. 3., that the equation (N.) is verified by any surface similar and concentric to the surface of the spheroid. A further simplification arises from the same property; for we may substitute the attraction of the matter within the interior surface, for the attraction of all the matter of the spheroid: so that the solution of the problem is reduced to the single condition of finding an elliptical surface to which the resultant of the attractive and centrifugal forces shall be perpendicular.

It may not be here improper to draw attention to the difference between the analysis of a problem, and its synthetic demonstration. In an analysis it is necessary to mount up to the essential principles of a problem, which always occupy a prominent place in the investigation; whereas a synthetic demonstration may proceed on properties previously investigated, and may be read and understood, although the essential grounds of the problem may never be brought into view. There is no doubt that it is the property cited above from the Principia, which makes the elliptical spheroid, exclusively of all other figures, the form of equilibrium of a homogeneous mass of fluid revolving about an axis; yet of this property no mention is made in MACLAURIN's demonstration. Nay, it has been contended on high authority that the property in question is merely accidental, and not essential to the equilibrium*. A little patience to have traced the property on which MACLAURIN's reasoning rests to its ultimate foundation, would have shown that, however the processes of investigation may be varied, they all originate from one source†.

Having now found the equations for determining *à priori* the figure of equilibrium of an incompressible fluid revolving about an axis, it remains to solve these equations.

PROBLEM III.

To solve the equations of the last problem.

Solution.—These equations are not easily solved without complicated calculations, at least if we proceed by direct methods.

The co-ordinates of a particle in a level surface being x, y, z the partial attractions parallel to x, y, z of the whole mass upon the particle, are represented in the equation (M.) by P, Q, R: and in the equation (N.), P′, Q′, R′ are the like partial attractions of the exterior stratum upon the particle: wherefore if P″, Q″, R″ denote the like partial attractions of the body of fluid within the level surface upon the particle, we shall have to solve these two equations,

$$\text{const.} = \int (\mathrm{P}'' dx + \mathrm{Q}'' dy + \mathrm{R}'' dz) + \tfrac{g}{2}(y^2 + z^2) \quad . \quad . \quad . \quad . \quad (\mathrm{M}'.)$$

$$\text{const.} = \int (\mathrm{P}' dx + \mathrm{Q}' dy + \mathrm{R}' dz) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (\mathrm{N}.)$$

the sum of which is the equation (M.).

* POISSON, Traité de Mécanique, No. 593.

† Vide Note, p. 248.

Let $d\mu$ be a molecule of the body of fluid within the level surface; x', y', z' the co-ordinates of $d\mu$; f the distance of $d\mu$ from the attracted particles in the level surface: then

$$f = \sqrt{(x - x')^2 + (y - y')^2 + (z - z')^2}.$$

The direct attraction of $d\mu$ upon the attracted particle is

$$\frac{d\mu}{f^2}.$$

the cosines of the angles which f makes with x, y, z, are respectively

$$\frac{x - x'}{f}, \frac{y - y'}{f}, \frac{z - z'}{f}:$$

wherefore the partial attractive forces parallel to x, y, z, acting upon the particle in the level surface in the directions in which the co-ordinates decrease, will be

$$d\mu \cdot \frac{x - x'}{f^3}, \quad d\mu \cdot \frac{y - y'}{f^3}, \quad d\mu \cdot \frac{z - z'}{f^3};$$

or, which are equivalent,

$$-d\mu \cdot \frac{d \cdot \frac{1}{f}}{dx}, \quad -d\mu \cdot \frac{d \cdot \frac{1}{f}}{dy}, \quad -d\mu \cdot \frac{d \cdot \frac{1}{f}}{dz}:$$

and, observing that x, y, z, are independent of $d\mu$, the like partial forces of all the molecules of the mass of fluid within the level surface, may be thus expressed:

$$-\frac{d \cdot \int \frac{d\mu}{f}}{dx}, \quad -\frac{d \cdot \int \frac{d\mu}{f}}{dy}, \quad -\frac{d \cdot \int \frac{d\mu}{f}}{dz},$$

the integral extending to all the molecules within the level surface. Now these forces are the same in quantity, but have contrary directions to the forces represented by P'', Q'', R'' in the equation (M'.); so that by substituting and then integrating, that equation will be thus transformed:

$$\text{const.} = \int \frac{d\mu}{f} + \frac{\varepsilon}{2}(y^2 + z^2).$$

Now the inspection of this equation is alone sufficient to show that, if it be verified in one curve surface, it will be verified in every curve surface similar and similarly posited about the central point. For assume two attracted points similarly situated in two such similar surfaces; divide the matter within the surfaces into the same number of infinitesimal molecules proportional to the masses within the surfaces; then, taking any molecules similarly situated with respect to the attracted points, the differential

$$\frac{d\mu}{f}$$

will be proportional to the square of the linear dimensions of the surfaces. This is evident; for the numerators are as the masses, or in the triplicate ratio of the linear

dimensions; and f representing similar lines of the surfaces, the denominators are simply as the linear dimensions. Wherefore the integral

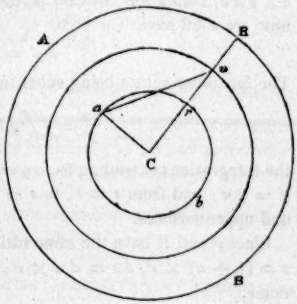
$$\int \frac{d\mu}{f},$$

extended to all the molecules within the surfaces, will be proportional to the square of the linear dimensions. Further, because the attracted points are similarly placed in the two surfaces, their co-ordinates will be similar lines; consequently

$$y^2 + z^2$$

will be as the squares of the linear dimensions of the surfaces. From what has been proved we learn that, for attracted points similarly situated in the surfaces, C will vary from one surface to another proportionally to the square of the linear dimensions of the surfaces; wherefore if C be constant at all the points of any one surface, it will be constant at all the points of every surface similar and similarly posited about the central point.

The solution of the equation (M′.) with respect to all the level surfaces, is now reduced to the verification of that equation by the upper surface of the fluid. When this condition is fulfilled, all the interior level surfaces, it has been demonstrated, are similar to the upper surface, and similarly posited about the central point.



We come next to turn our attention to the equation (N). Let A R B represent the surface of the fluid in equilibrium; C the central point; $a\,r\,b$ a level surface similar to A R B, and similarly situated about C; further, a being an attracted point in the level surface, and u a point of the stratum between the two surfaces, put x, y, z for the co-ordinates of a, and x', y', z' for those of u; then f being the distance from a to u, we shall have

$$f = \sqrt{(x - x')^2 + (y - y')^2 + (z - z')^2}.$$

Let $d\,\mu'$ represent a molecule of the stratum at the point u; the direct attraction of $d\,\mu'$ upon a particle at a, will be

$$\frac{d\,\mu'}{f^2}:$$

and by proceeding as before it will be found that the partial forces parallel to x, y, z, caused by the attractions of all the molecules of the stratum upon the particle, and estimated in the directions in which the co-ordinates increase, are as follows:

$$\frac{d \cdot \int \frac{d\mu'}{f}}{d\,x}, \quad \frac{d \cdot \int \frac{d\mu'}{f}}{d\,y}, \quad \frac{d \cdot \int \frac{d\mu'}{f}}{d\,z}.$$

Now these are the forces represented by P′, Q′, R′ in the equation (N.): so that, by substituting and integrating, that equation will be changed into this which follows:

$$\text{const.} = \int \frac{d\mu'}{f},$$

the integral extending to all the molecules of the stratum.

The co-ordinates at the points a and u, are thus expressed:

$$\begin{aligned} C\,a = r &= \sqrt{x^2 + y^2 + z^2} & C\,u = s &= \sqrt{x'^2 + y'^2 + z'^2} \\ x &= r\cos\theta & x' &= s\cos\theta' \\ y &= r\sin\theta\cos q & y' &= s\sin\theta'\cos q' \\ z &= r\sin\theta\sin q & z' &= s\sin\theta'\sin q', \end{aligned}$$

in which formulas, θ, θ' are the angles that r and s make with the axis of rotation; aud q, q' the angles that determine the position of the projections of r and s upon the plane of $y\,z$. By substituting the values of the co-ordinates we obtain

$$f = \sqrt{s^2 - 2\gamma r . s + r^2},$$
$$\gamma = \cos\theta\cos\theta' + \sin\theta\sin\theta'\cos(q - q').$$

If the variables s, θ', q' change to $s + d\,s$, $\theta' + d\,\theta'$, $q' + d\,q'$, the three small lines $d\,s$, $s\,d\,\theta'$, $s\sin\theta'\,d\,q'$, will be perpendicular to one another; and, as the density is unit, we shall have

$$d\,\mu' = s^2\,d\,s\,.\,d\,\theta'\,d\,q'\sin.\theta'.$$

The foregoing values being substituted, this result will be obtained,

$$\int \frac{d\,\mu'}{f} = \iint d\,\theta'\,d\,q'\sin\theta' \int \frac{s^2\,d\,s}{\sqrt{s^2 - 2\gamma r . s + r^2}},$$

the integrations extending from $\gamma = 1$ to $\gamma = -1$; and from $\theta' = 0$, $q' = 0$, to $\theta' = \pi$, $q' = 2\pi$; and from $s = r'$, to $s = R$, r' and R being the values of s at the interior and upper surfaces.

Since r' and R have the same ratio in every position of the line C r' R, we may put $s = (1 + \alpha) \times r'$, $d\,s = d\,\alpha \times r'$; by which substitutions the last equation will become,

$$\int \frac{d\,\mu}{f} = \iint d\,\theta'\,d\,q'\sin\theta' . \int (1 + \alpha)\,d\,\alpha\,.\,\frac{r'^2}{\sqrt{1 - 2\gamma\frac{r}{r'(1+\alpha)} + \frac{r^2}{r'^2(1+\alpha)^2}}}$$

the quantity α being constant at all the points of an exterior surface similar to the level surface, but varying from one exterior surface to another. The radical quantity must next be expanded in a series of the powers of $\frac{r}{r'(1+\alpha)}$, viz.

$$1 + C^{(1)} \cdot \frac{r}{r'(1+\alpha)} + C^{(2)} \cdot \frac{r^2}{r'^2(1+\alpha)^2} + C^{(3)} \cdot \frac{r^3}{r'^3(1+\alpha)^3} + \&c.,$$

the coefficients being determined by the well-known formula,

$$C^{(i)} = \frac{1}{2^i} \cdot \frac{d^i (\gamma^2 - 1)}{1.2.3 \ldots i \times d\gamma^i}.$$

This expansion is admissible; for $(1 + \alpha)\, r'$ being the radius of a surface exterior to the level surface, $\frac{r}{r'(1+\alpha)}$ will be less than unit, and the series will always converge. By substituting the series, we get,

$$\begin{aligned}
\int \frac{d\mu'}{f} = & \int_0^\alpha (1 + \alpha)\, d\alpha \,.\, \iint d\theta\, dq' \sin\theta \,.\, r'^2 \\
& + r \,.\, \alpha \iint d\theta\, dq' \sin\theta \,.\, r'\, C^{(1)} \\
& + r^2 \int_0^\alpha \frac{d\alpha}{1+\alpha} \cdot \iint d\theta\, dq' \sin\theta \,.\, C^{(2)} \\
& + r^3 \int_0^\alpha \frac{d\alpha}{(1+\alpha)^2} \cdot \iint d\theta\, dq' \sin\theta \,.\, \frac{C^{(3)}}{r'} \\
& \quad . \\
& \quad . \\
& \quad . \\
& r^i \int_0^\alpha \frac{d\alpha}{(1+\alpha)^{i-1}} \cdot \iint d\theta\, dq' \sin\theta \,.\, \frac{C^{(i)}}{r'^{(i-2)}}.
\end{aligned}$$

As $\int \frac{d\mu'}{f}$ must have the same value at all the points of the level surface, it must be independent of r, which varies with the position of the attracted point; and hence we learn that all the terms of the foregoing series containing r, or any power of r, must be separately equal to zero. This brings the question to the two following equations: first,

$$\int \frac{d\mu'}{f} = \int_0^\alpha (1 + \alpha)\, d\alpha \,.\, \iint d\theta\, dq' \sin\theta \,.\, r'^2,$$

which ascertains the quantity of $\int \frac{d\mu'}{f}$, resulting from the attraction of a stratum contained between the similar surfaces, of which the radii are r' and $r' \,.\, (1 + \alpha)$, and such that $\int \frac{d\mu'}{f}$ has the same value for all positions of the attracted point in the level surface; secondly, the equation

$$0 = \iint d\theta\, dq' \sin\theta \cdot \frac{C^{(i)}}{r'^{(i-2)}}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (O.)$$

for all values of i from 1 to ∞, which determines the expression of r', and the nature of the spheroid. It now only remains to solve this equation.

Whatever figure the spheroid sought may be supposed to have, the equation of its

surface will be a function of the three co-ordinates of a point of that surface: and the expression of a radius r' deduced from that equation, can only be a function of the three quantities

$$\cos\theta', \quad \sin\theta'\cos q', \quad \sin\theta'\sin q', \quad \text{or } a', b', c',$$

which determine the position of r'. We may suppose that r', or any power of r' positive or negative, is either exactly or approximately a rational function of a', b', c'; and the terms of every such function may be so arranged as to come under this form of expression:

$$U^{(0)} + U^{(1)} + U^{(2)} \ldots . + U^{(n)},$$

$U^{(0)}$ being a constant, and $U^{(n)}$ representing generally a homogeneous function of a', b', c' of n dimensions. By means of this notation we obtain the following theorems:

$$\text{I. } 0 = \int_0^{\pi}\int_0^{2\pi} d\theta'\, dq' \sin\theta' \,.\, U^{(n)}\, C^{(i)}$$

in all cases when n is less than i:

$$\text{II. } 0 = \int_0^{\pi}\int_0^{2\pi} d\theta'\, dq' \sin\theta'\, U^{(n)}\, C^{(i)}$$

when n is an even number, and i an odd number.

These theorems relate to a branch of analysis that has been much cultivated; and as they are easily deduced from well-known properties, the demonstrations are omitted for the sake of abridging.

According to what has been said,

$$r' = U^{(0)} + U^{(1)} + U^{(2)} \ldots . U^{(n)};$$

and if we make $i = 1$, $C^{(1)} = \gamma$, the equation (O.) will become

$$0 = \iint d\theta'\, dq' \sin\theta' \,.\, \{\gamma\, U^0 + \gamma\, U^{(1)} + \gamma\, U^{(2)} \ldots . + \gamma\, U^{(n)}\}.$$

Now, by the second theorem, all the terms in which n is an even number will be zero; and hence, in order to make the whole expression zero, all the other terms in which n is an odd number must be exterminated. Thus the value of r' that will verify the equation (O.) is as follows:

$$r' = U^0 + U^{(2)} + U^{(4)} \ldots . + U^{(2n)}.$$

Every power of r' positive or negative will be of the like form, so that

$$\frac{1}{i-2} = U^0 + U^{(2)} + U^{(4)} \ldots . + U^{(2n)};$$

and, by the second theorem, this expression will verify the equation (O.) in all cases when i is an odd number.

As the equation (O.) does not contain r' when $i = 2$, it is obviously verified in that case. When $i = 4$ we have

$$\frac{1}{r'^2} = U^0 + U^{(2)} + U^{(4)} +, \&c.;$$

and the equation (O.) will take this form,

$$0 = \int\int d\theta' \, dq' \sin\theta' \, . \, \{U^0 \, C^{(4)} + U^{(2)} \, C^{(4)} + U^{(4)} \, C^4 +, \&c.\};$$

of which expression the two first terms are zero by the first theorem; but as the succeeding terms have all determinate values, they must be cancelled, which limits the expression of $\frac{1}{r'^2}$ that will verify the equation (O.) to

$$\frac{1}{r'^2} = U^{(0)} + U^{(2)}.$$

We have now only to inquire whether the expression of $\frac{1}{r'^2}$ thus found will verify the equation (O.) in all cases when i is an even number greater than 4: now

$$\int\int d\theta' \, dq' \sin\theta' \frac{C^{(i)}}{r'^{(i-2)}} = \int\int d\theta' \, dq' \sin\theta' \, . \, C^i \, (U^0 + U^{(2)})^{\frac{i}{2} - 1}:$$

and i being any even number, if the binomial quantity be expanded and arranged in homogeneous functions, it will be of this form,

$$U^{(0)} + U^{(2)} + U^{(4)} \ldots + U^{i-2},$$

the substitution of which will produce a series of terms, every one of which will vanish by the first theorem.

The foregoing investigation proves that every figure capable of fulfilling the conditions required for the equilibrium of an incompressible fluid subject to the law of attraction that prevails in nature, and revolving about an axis, is comprehended in the formula

$$\frac{1}{r'^2} = U^{(0)} + U^{(2)}.$$

Taking the most general expression of $U^{(2)}$, which stands for a homogeneous expression of two dimensions, of $\cos\theta'$, $\sin\theta' \cos q'$, $\sin\theta' \sin q'$, or a', b', c'; and observing that the constant

$$U^0 = U^0 \, . \, a'^2 + U^0 \, . \, b'^2 + U^0 \, . \, c'^2,$$

may be blended with the expression of $U^{(2)}$, we shall have

$$\frac{1}{r'^2} = A \, a'^2 + B \, b'^2 + C \, c'^2 + D \, a' \, b' + E \, a' \, c' + F \, b' \, c':$$

and as $r' \, a'$, $r' \, b'$, $r' \, c'$ are the co-ordinates of a point in the surface of the fluid, we obtain this general equation:

$$1 = A \, x'^2 + B \, y'^2 + C \, z'^2 + D \, x' \, y' + E \, x' \, z + F \, y' \, z',$$

which is that of an ellipsoid, the co-ordinates being parallel to any three diameters intersecting at right angles. This general equation is modified by the rotatory mo-

tion; for it is easy to prove that the axis about which the fluid revolves, or the diameter parallel to the co-ordinate x', must be perpendicular to the surface of the fluid, and consequently it must be one of the axes of the ellipsoid: and as nothing hinders from assuming the other two axes for the diameters to which the co-ordinates y and z are parallel, the foregoing equation will take this more simple form:

$$1 = A\,x'^2 + B\,y'^2 + C\,z'^2 = \frac{x'^2}{k^2} + \frac{y'^2}{k'^2} + \frac{z'^2}{k''^2},$$

the three semi-axes of the ellipsoid being k, k', k'', of which k is the axis of rotation. Thus the ellipsoid comprehends every possible figure of equilibrium, the rotatory motion being performed about one of the axes. When the centrifugal force is given, the particular figure of equilibrium is found by making the resultant of the attractive and centrifugal forces perpendicular to the surface of the ellipsoid.

Note of Mr. IVORY *relating to the correcting of an error in a Paper printed in the Philosophical Transactions for* 1838, pp. 57, &c.

IN the paper referred to* it is said, "Let V stand for the integral in the equation (7.), and supposing that p and τ^2 vary so as always to satisfy that equation, we shall have

$$\frac{d\,\mathrm{V}}{d\,p}\,d\,p + \frac{d\,d\,\mathrm{V}}{\tau\,d\,\tau} = 0."$$

Now the error alluded to consists in having given a wrong sign to the differential $\frac{d\,\mathrm{V}}{\tau\,d\,\tau}$, the value of which, as has been said, is modified, in the question under consideration, by the equation (7.). This mistake vitiates the concluding part of the paper in pp. 63, 64, 65, as far as relates to the limits of the quantities p and τ^2. M. LIOUSVILLE has done the author of the paper the honour of noticing and correcting the mistake in his *Journal de Mathématiques for April* 1839. When the sign of the differential is rightly ascertained, the analysis pursued in the paper leads to a simple determination of the limits sought, as this Note will prove, the propriety of printing which in the Philosophical Transactions is submitted to the Council.

For the sake of abridging expressions, put

$$\Delta^2 = (1 + p\,x^2)^2 + \tau^2\,x^2, \quad \mathrm{P}^2 = (1 + p)^2 + \tau^2;$$

then

$$(1 - x^2)\,(1 - p^2\,x^2) = \Delta^2 - \mathrm{P}^2\,x^2.$$

By substituting this value in equation (7.),

$$\mathrm{V} = \int_0^1 \frac{x^2\,d\,x}{\Delta} - \mathrm{P}^2 \int_0^1 \frac{x^4\,d\,x}{\Delta^3},$$

$$\frac{d\,\mathrm{V}}{\tau\,d\,\tau} = -\,3\int_0^1 \frac{x^4\,d\,x}{\Delta^3} + 3\,\mathrm{P}^2 \int_0^1 \frac{x^6\,d\,x}{\Delta^5};$$

and hence

$$\mathrm{V} + \frac{\mathrm{P}^2}{3} \cdot \frac{d\,\mathrm{V}}{\tau\,d\,\tau} = \int_0^1 \frac{x^2\,d\,x}{\Delta} \left(1 - \frac{\mathrm{P}^2\,x^2}{\Delta^2}\right)^2;$$

which proves that the same values of p and τ^2 that make $\mathrm{V} = 0$, will necessarily make $\frac{d\,\mathrm{V}}{\tau\,d\,\tau}$ positive.

Further, we have

$$\frac{d\,\mathrm{V}}{d\,p} = -\int_0^1 \frac{x^4\,(1 - x^2)\,d\,x}{\Delta^5} \left\{ (3 + 2\,p - p^2\,x^2)\,(1 + p\,x^2) + 2\,p\,\tau^2\,x^2 \right\};$$

from which it follows that, whatever positive number τ^2 stands for, $\frac{d\,\mathrm{V}}{d\,p}$ is negative for

* Philosophical Transactions, 1838, p. 63.

all values of p that make $3 + 2p - p^2$ positive, that is, for all values of p less than 3.

The function V is positive when $p = 1$; it is zero when $p = l^2$ and $\tau^2 = 0$. And, if we suppose that p decreases from l^2 to 1, while τ^2 increases from 0 to ∞, the differential equation (A.) will in no instance be verified; because, according to what has been shown, both the terms of the equation will be positive between the limits mentioned. Thus there is no value of p less than l^2 that will verify the equation (7.).

It is proved in the paper (p. 62) that for every assumed value of τ^2, there is a positive value of p, that will verify the equation (7.); and, as it has now been shown that the values of p which verify that equation cannot be less than l^2, they must be all greater than l^2.

Further, in the differential equation (A.), $\frac{dV}{dp}$ cannot be zero; because, τ^2 increasing without limit, $\frac{V}{\tau\, d\tau} \cdot \tau\, d\tau$ is essentially positive. Now, for all values of p between l^2 and 3, $\frac{dV}{dp}$ is negative; wherefore the same function will continue to be negative in the equation (A.) for all values of p and τ^2: and as $\frac{dV}{dp}\, dp$ is also negative, dp must be positive, so that p will increase above l^2 without limit.

If the sign of $\frac{dV}{dp}$ be changed, the result will be positive; and hence, observing that x is contained between 0 and 1, we obtain a condition between any two values of p and τ^2 that satisfy the equation (7.), namely, the expression

$$(3 + p - p^2)(1 + p) + 2p\tau^2$$

must be a positive quantity, or, which is the same thing,

$$\tau^2 > (p^2 - p + 3) \cdot \frac{1 + p}{2p}.$$

J. Ivory.

July 25, 1839.

XVI. *Report of a Geometrical Measurement of the Height of the Aurora Borealis above the Earth. By the Rev.* James Farquharson, *LL.D. F.R.S., Minister of the Parish of Alford. Communicated by Major* Sabine, *R.A. F.R.S. &c.*

Received May 30,—Read June 20, 1839.

When, in 1833, I observed the "instructions for observers of the aurora borealis," circulated by the British Association for the Advancement of Science, I became desirous of aiding in the attainment of the objects the Association have in view; the chief of which are, the determination by geometrical measurement of the height of the meteor above the earth, and of the altitude and azimuth of the point to which the streamers seem to converge, and which has been named the centre of the corona.

The full accomplishment of my purpose has been delayed by impediments, the chief of which will be referred to in the progress of this Report. I have, however, at length obtained such results as I conceive will be deemed of importance, and I beg leave respectfully to present them to the notice of the Royal Society.

I had soon an opportunity for determining, with sufficient accuracy, the altitude and azimuth of the point in the heavens to which the streamers seem to converge; and as this constitutes an important element in enabling us to form a clear conception of the whole definite arrangement and progress of the meteor, and of the extent of reliance to be placed on the method afterwards had recourse to for measuring the height above the earth, and as that distinguished observer, Major Sabine, has since determined the dip of the magnetic needle at this place, which agrees with the angle of altitude of the point of convergence of the streamers, I shall proceed, first, to detail, from my notes made at the time, my observations on this point.

On the 29th December, 1833, during the progress of a hard gale at nearly due west, temperature 42° Fahr., there occurred here an aurora borealis, more nearly than any other I have seen, like the one seen by me here on the 29th of September, 1828, contemporaneously with a luminous arch seen by Davies Gilbert, Esq. P.R.S., at Rosemorran in Cornwall, as described by me in a letter to the President, which was honoured with a place in the Philosophical Transactions*. The chief difference of the two consisted in there being, on the 29th of December, 1833, many more arches of great length from east to west, well-defined, and separated, when in the plane of the magnetic dip, by clear lanes, from all the other arches and lights in other parts of the sky.

* Philosophical Transactions, 1829, pp. 103–120.

At 6 P.M. innumerable groups of brilliant streamers, and nebulous patches of light, appeared in almost all parts of the sky, but arranged into narrow arches, with clear lanes between them, near the plane of the magnetic dip. The sky was clear of clouds, with the exception of one cloud of low elevation at south-east. When the meteor was first noticed, there was one narrow distinct arch, almost continuous from the eastern to the western horizon, a little north of, and parallel to, the plane of the magnetic dip. This arch made a rapid progress southward, always preserving its parallelism to the plane of the magnetic dip, and in four or five minutes passed into that plane, where its vertex presented the appearance named by observers a corona, well-defined and brilliant. The appearance of the corona is that of innumerable pencils, or brushes of light radiating in all directions from a centre. In the present instance the pencils pointing northward and southward were short, ending at the edges of the arch, which was only 4° or 5° broad; and those that pointed eastward and westward became blended with the streamers which formed its east and west ends. A small space in the centre of the corona had a nebulous, rather than radiated appearance. This was only about one degree broad, but prevented the determination of the centre, excepting by approximation within half a degree.

At the moment when, in the southward progress of the arch, the centre of the corona became best defined, I had a good resource at hand for determining its place in the heavens, approximately, within such limits as the nebulous centrical light allowed. This consisted in marking, on an outside stair rail, the precise point from which the centre of the corona was exactly seen, over an extreme projecting point on one of the corners of the Manse here.

The distinct arch of the aurora now described, continued to make a rapid progress southward, preserving always a parallelism with its earlier positions, and with the plane of the magnetic dip. The short streamers to the north of the centre of the corona became more shortened; and those to the south of it became proportionally longer, preserving in this way the vertex of the arch of a mean breadth with that of the other parts of it, till at length the corona lost the whole rays that had a northerly direction. The whole arch, as it went on still further towards the south, became gradually enlarged in its lateral dimensions, that is, in breadth from north to south, as I have described other arches to have done, in the letter to the President of the Royal Society above referred to.

My attention was soon withdrawn from this arch by another now approaching the zenith from the north. This was composed of much more brilliant streamers than the former. It was considerably wider from north to south, and less evenly defined at its north and south edges, appearing there fitfully rugged, but quite distinctly separated from the numerous other lights in the sky by lanes clear of any form of the meteor. Expecting that it too would pass southward, and form a corona, when it reached the position where the other had done so, I provided a long straight-edged ruler, to ascertain by it whether the streamers in all parts of the sky were directed

to the centre of the corona. The arch soon passed southward into the plane of the magnetic dip, narrowing in breadth till it reached that position, and forming when there a corona, exactly like the former one, the centre of which had the same altitude and azimuth. On looking at the centre of the corona over the straight edge of the ruler at one of its ends, while it was held out at arm's length, and at the same time bringing the other end round to all parts of the sky, it was found that everywhere the streamers were directed lengthwise to the centre of the corona.

This latter arch passed southward as the former had done; and like it also, increased its breadth from north to south in its onward progress from the plane of the dip. It was succeeded by many other arches and fragments of arches, that is, arches cut short in their east and west dimension, all of which behaved themselves in a manner analogous to the two first arches, or to corresponding portions of them. About an hour and a half after the aurora was first seen, the phenomena became faint at all points, and the sky soon after became obscured by clouds.

On the day following these observations, I measured, by means of a small graduated semicircle, with plummet, the angle that the line, joining the mark on the stair rail and the projecting point on the corner of the Manse, made with the horizon, and found it about 72°. Major SABINE afterwards, on the 27th and 29th of August, 1836, by 160 readings of his dipping-needle, determined the dip at this place to be then 72° 19′·5 *. I also laid down a horizontal line in the azimuth of the two points; and having suspended over it, by means of a silk fibre, a horizontal magnetic needle, found that the needle came to rest parallel to the line.

It has been a matter of more difficulty to arrange the means, and find a fit opportunity, to determine the height above the earth, by the method recommended by the British Association, namely, by instrumental measurements of the angular elevations of an arch, made contemporaneously at two stations on the magnetic meridian, sufficiently distant from each other to give a clear and satisfactory parallax.

With the view of effecting this, I entered into arrangements with a gentleman whose residence is about six miles north of this place, and very near its magnetic meridian. There intervenes the ridge of the Coreen hills, extending in length from east and west about ten miles, in breadth from north to south about four miles, and elevated at many points about 1000 feet above the level of the two stations. After looking out for some years for corresponding observations of the same arch, although there was no want of appearances of the aurora, the gentleman and I found that the observed conditions and circumstances were so discrepant, as to prohibit the inference that we had at any time witnessed the same phenomenon. We had agreed that each should observe to the northward of his own station.

In the mean time I obtained information which I deemed highly valuable for determining the locality of the stations that might be next selected. The Rev. JOHN MINTO, a native of this parish, and schoolmaster of Clatt, which is on the north side

* Major SABINE's Observations on the Direction and Intensity of the Magnetic Force in Scotland, 1836.

of the Coreen hills, had frequent occasion to pass between this place and Clatt. His path over the hills is, at its most elevated part, nearly in the line of the magnetic meridian. He informed me that he had passed in this line several times after dark, on occasions when the aurora borealis was visible. At these times he had travelled in the northerly direction only; but after seeing the whole meteor to the northward of his place, while ascending the south side of the highest part of his path, when he reached the valley on the north side, he then saw the aurora wholly to the south, and at such a low elevation as could not be accounted for by the known movement of the meteor itself, without taking into account its apparent change of place occasioned by his own movement northward. This circumstance occurred to him several times; and he became impressed with the conviction, that the place of the meteor on these occasions was the Coreen hills, and that it was at no great elevation above them. Mr. MINTO's conclusion coincided with those I have had reason to form, from many observations of the meteor, respecting the lowness of the region in which it is visible; and admitting the conclusions to be correct, it became obvious that the two stations, from whence to determine its height, would be both most expediently chosen on one side of the ridge of hills. This choice of stations was therefore had recourse to, and with a completely satisfactory result, as will be afterwards stated.

But previously to presenting the observations that were made at the selected stations, it seems necessary, for a right appreciation of their value, to make some remarks on an obvious misapprehension that yet seems to be entertained of the arrangement and progress of the aurora. I had shown that its arrangement and progress are definite in relation to the lines of magnetism of the earth, in a paper published in the Edinburgh Philosophical Journal in April, 1823*, and afterwards in the letter addressed to the President of the Royal Society, and published in the Philosophical Transactions, 1829, above referred to. In the latter publication, after describing various appearances of the aurora, I stated that these appearances indicated the following necessary results:—

"1st. That the aurora borealis always presents itself in definite and very curious relations to the lines of magnetism indicated by the needle.

"2nd. That the streamers, in the direction of their length, coincide with the plane of the dip of the needle, or nearly so; and that each individual streamer is, in fact, parallel to the dipping-needle.

"3rd. That they [the streamers] form a thin fringe, stretching often a great way from east to west at right angles to the magnetic meridian.

"4th. That the fringe moves away from the north magnetic pole, by the extinction of streamers at its northern face, and the formation of new ones, contiguous to its southern face.

"5th. That the invariable regularity of its appearance, as seen by many observers, when it comes fully within command of the eye near the zenith, shows the apparent

* Vol. viii. p. 303.

irregularities, when it is seen either more northerly or southerly, to be only optical illusions.

"6th. That the region which it occupies is above, and contiguous to that of the clouds, or that in which they are about to form."

Some terms employed in the "Instructions" of the British Association, and some also employed by M. Arago, in a passage of his printed in the Edinburgh New Philosophical Journal*, show, that these inductions of mine, regarding the arrangement and progress of the meteor, have been misunderstood or not admitted as accurate. In the "Instructions" it is said, "the determination of elevation can scarcely be applied to streamers of aurora, except when some sudden incurvation, or change, occurs which may happen to be noticed at two stations; but the arches are of a less evanescent nature." This obviously implies that the streamers and the arches are two distinct and unconnected branches of the phenomena. The terms of M. Arago imply the same thing. He says, "when in our climates the aurora borealis is complete, when one part of its light pictures on space a well-defined arch, the culminating point of *this arch* is in the magnetic meridian; and its two points of apparent intersection with the horizon are at equal angular distances from the same meridian. When it projects luminous columns, [by which he evidently means streamers,] from different portions of the arch, their point of intersection, called by certain meteorologists the centre of the cupola, is found in the magnetic meridian, and precisely upon the prolongation of the dipping needle." Here too the arches and the streamers are considered as distinct objects. But an *arch* of the aurora is composed of a number of *streamers* grouped and aggregated together within a defined stereometric space, whose bounding planes bear certain relations to the lines of magnetism of the earth. It is this fact that I announced in the Edinburgh Philosophical Journal in 1823, and afterwards in the letter to the President of the Royal Society; and if the arrangement is not yet understood, it may have been owing to a misapprehension of the terminology I employed; or, more probably, to my not having, in the letter to the President, entered into a detail of the varieties of the arches that often present themselves, as I had done in the Edinburgh Journal. I would endeavour now to supply the deficiency, by defining the terms, and entering into some more detail of the varieties, or rather apparent varieties of the arches; for the numerous observations of the aurora I have since made, convince me more fully of the existence of that definite order of its arrangement and progress which I have formerly described, and that it is worthy of being understood, however much I may have hitherto failed clearly to explain it.

The terms *arch* and *streamer* of the aurora, I had used without defining them, because I conceived them to be in common use among observers; and I shall now perhaps be able best to define them, after presenting anew one part of the description of the whole meteor, which I had given in the Edinburgh Philosophical Journal

* Vol. xxv. p. 419. I regret that I cannot more particularly indicate M. Arago's publication, having seen the passage only in the Magazine.

in 1823, which is as follows. "In this latitude, (about 57° 12′ N.) the aurora borealis, on those evenings when it is visible, *generally* first shows itself, after dark, like a bright but circumscribed twilight on the visible horizon, the centre of which is exactly on the northern point of the magnetic meridian. So long as the bright space continues low, its light often nearly resembles the pale blue white light of the real twilight; but varies momentarily by incessant and undefined fits of gleaming and obscuration. By degrees the meteor enlarges itself, rising higher, and extending more from east to west on the horizon. The play of the fitful gleaming light becomes gradually better defined; and the whole luminous space presents the appearance of pencils, or bundles, of rays pointing upwards, and, when viewed in narrow compartments, maintaining a parallelism among themselves, similar to that exhibited by the rays of the sun when he shines through broken clouds athwart a hazy atmosphere. The rays which are on the magnetic meridian are parallel to that line, pointing exactly to the zenith; and those which are considerably to the eastward or westward of that meridian are directed to a point which appears within the limits of 10° [18°] to the southward of the zenith. The bluish white light changes into a beautiful pale green, which when the meteor rises quite above the horizon, as will be afterwards described, becomes tinged at the lower extremity of the rays with blue and violet, and at their upper extremity with yellow and orange. The rays are very various in their intensity of light, as compared with one another; their higher and lower portions also frequently differ from each other in that respect; and the whole appearance of each ray varies incessantly. It now breaks off, and disappears for a considerable space at its higher or lower extremity, and then immediately becomes again luminous to its former extent; now seemingly runs from east to west or from west to east through 5° or 10° or 12°, during the space of a second or two, preserving correctly its parallelism with other rays, which it approaches or passes in its progress; then remains stationary for a second or two, undergoing various changes of vividness; and afterwards disappears instantaneously, to have its place supplied by another ray, created as rapidly as its predecessor was annihilated. This magnificent and beautiful light gradually extends itself towards the south, and at length separates itself from the northern horizon at the point of the magnetic meridian, and forms a flat luminous arch in the northern part of the heavens. The arch still goes on to make progress towards the south, its convex or upper part approaching the zenith, and its concave or lower side becoming more widely separated from the horizon. When it reaches an elevation of about 45°, it presents the appearance of a broad [curved] zone, occupying from north to south the space of from 25° to 35° at its vertex, and having its eastern and western extremities resting on the visible horizon."

In this passage, both the streamers and the arch of the aurora are described. The streamers are the narrow pencils, or bundles, of rays whose upper extremities are directed to that point in the heavens which forms the upper prolongation of the line of the dipping needle. They are severally in a state of incessant extinction and reno-

vation. An arch is the curved zone of light formed by an aggregation or grouping of a great number of streamers into a definite form. Although composed entirely of parts (streamers) which are severally evanescent, yet the perpetual renewal of these within a definite space, or in a definite direction in relation to the place of the extinct ones, renders the arch relatively permanent; and it often continues for several hours, shifting however gradually towards the south.

In continuation of the above passage taken from the Edinburgh Philosophical Journal, I had described the further progress of such an arch as that mentioned in it, and shown, that it passes at length into the plane of the magnetic dip, gradually contracting its breadth, from north to south, as it nearly approaches that plane, the streamers of which it is composed still pointing, in every part of it, to the point which is on the prolongation of the dipping needle; and that, when it at last reaches the plane of the magnetic dip, it forms a narrow zone, seldom exceeding 4° or 5° from north to south, stretching across the heavens at right angles to the magnetic meridian, and composed now, in its east and west ends, of streamers which no longer cross its breadth, as they did while it was in a more northerly position, but are parallel to the zone itself, and therefore pointing east and west. In that journal, I had added to the description of the arrangement and progress of the longer and more complete arches that present themselves, a description of some of the varieties, or shorter arches, which at various times occur, either by themselves, or mingled up with the longer arches. I shall quote from the Edinburgh Philosophical Journal the account I had given of these varieties, because, in the letter to the President of the Royal Society, I neglected to describe them along with the more lengthened arches; and the neglect may have occasioned misapprehension of the whole subject on the part of those who have seen only the letter to the President.

In the Edinburgh Journal, after a description of the more lengthened arch, and its progress, it is added, "such is the order of appearances presented by the aurora borealis, when it is observed under the most favourable circumstances. It is very seldom, however, that all the successive phenomena, now described, have been observed continuously on the same evening; but those observed at any one particular time have always been entirely consistent with the above description; and I shall now enter a little into a detail of the varieties which present themselves. It very frequently happens, that the twilight-like appearance on the northern horizon is all that is visible, and the phenomenon begins and ends with that. In this case the meteor is seldom of long continuance; but during the time that it lasts, the luminous space gradually enlarges itself towards the south. It then gradually disappears; frequently to be succeeded by another, appearing low on the horizon, to enlarge, and afterwards disappear, as its predecessor had done. It happens also, very frequently, that, even when it makes more progress towards the south, it becomes gradually extinct long before it reaches the zenith; for it is liable to a total extinction in every stage of its advancement; but while it does continue, it follows the order above described, presenting the longest

pencils of rays when about 45° elevation, and more dense, compact and shorter ones near the zenith. It also very frequently happens that the meteor is suddenly formed high above the horizon, at first by feeble detached rays, becoming quickly more condensed and luminous. But in whatever stage it first begins, the succeeding relative progress is the same as above described. It was chiefly those meteors, which were first formed above the horizon, that were observed to pass over the zenith. Those formed further northward generally disappeared before reaching that point. There is another modification of these appearances, and that is, when the meteor is entirely to the eastward or westward of the magnetic meridian; and this is of not unfrequent occurrence. In this case, the appearance and progress of the whole exactly agree with those of corresponding portions of the above described zone, which is formed when the meteor extends across the magnetic meridian. The extremity of the luminous space which is nearest the magnetic meridian becomes first elevated above the horizon; the pencils of rays are directed, longitudinally, to a point a little south of the zenith; and the meteor moves gradually towards the south, contracting gradually its lateral dimensions as it reaches the prime vertical to the magnetic meridian, where it assumes the appearance of a nearly vertical column of brilliant light, 3° or 4° in diameter, composed of pencils of rays parallel to itself. After passing some degrees to the southward of the prime vertical, the meteor begins to enlarge gradually in width, in an order the reverse of that in which it had become narrowed. Some other apparent irregularities have been at times observed. Thus the pencils of rays have sometimes been seen separated into detached groups; but each group consistent in its appearance and position with those of the other groups, so that, had the spaces between them been filled up, a complete zone, such as above described, would have been formed. A detachment into distinct groups sometimes takes place immediately previous to the disappearance of the meteor; but sometimes also it is not immediately followed by that disappearance, but the zone becomes again complete, or nearly so, at a further stage of the progress southward. But no [real] anomalies have been at any time observed; nothing that is inconsistent with the described order of the phenomena*."

In addition to this detail of the varieties taken from a former description, it seems necessary here to add, that although the most frequent appearance of the meteor consists of one, or a few regular zones behind each other in a north and south direction, of great length from east to west, yet sometimes, as on the evenings of the 29th September 1828, and 29th December 1833, the lengthened zones are accompanied with

* Major Sabine, while here in 1836, and observing the range of the Coreen hills, northward of this place, to run exactly at right angles to the magnetic meridian, suggested that the great regularity of the appearance and progress of the aurora here might be dependent on that circumstance. The suggestion is highly worthy of attention. The natural tendency of the meteor to the described order may be aided by the position of the hills; and hence a peculiar regularity here; but that the tendency is not altogether dependent on the locality, is proved by the crown of a lengthened arch being, in all places in Britain, on the magnetic meridian, and by the narrowness of the zone of light in the plane of the dip, as witnessed and reported by many observers.

all the described varieties, placed in the intervals between them. The whole hemisphere is, in such instances, pervaded by the meteor; and, on looking northward or southward, no regularity in the arrangement can be readily distinguished. But on looking up in the plane of the magnetic dip, the described order is there immediately discovered. The meteor there presents the appearance of intermingled longer or shorter narrow belts of fitful light, at right angles to the magnetic meridian, or columns at the east or west, having all clear intervals between them, and all making progress towards the south, preserving at the same time their parallelism with each other. It seems also necessary to add, that the light of the several belts differs greatly in intensity; some being composed of closely crowded and very brilliant streamers, and others of a few feebly-lighted, ill-defined ones.

It is now apparent, from the description, that the streamers are not phenomena distinct from the arches, but that the latter are just aggregations of the former within certain stereometric spaces, whose bounding planes bear definite relations to the lines of magnetism of the earth. In the letter to the President of the Royal Society I named these aggregations fringes; and, in fact, they resemble long fringes composed of threads, the threads being represented by the individual, nearly vertical streamers, or lengthened narrow straight pencils of rays of light. The length of these filled stereometric spaces, at right angles to the magnetic meridian, is often very many miles, extending over head, when they come to the zenith, from the east to the west horizon, although they are frequently cut short in this dimension. Their depth in a nearly vertical direction, or more properly in the plane of the magnetic dip, is determined by the length of the individual streamers that fill them. This length of the streamers seems to vary considerably; as some of the arches at about 45° elevation may be seen about 20° broad from north to south, and others 30° and upwards. The streamers in the same space, too, are not equal in length among themselves, their inequality in this respect causing the jagged appearance of the north and south edges of the arches; but in this respect also there are great differences, the edges of some arches, especially on very calm evenings, being even and regularly defined. The thickness of the filled spaces from north to south appears to be always much less than their depth in the plane of the magnetic dip. This thickness from north to south is clearly seen when the meteor comes into that plane, in its progress southward. When there, an arch that at 45° elevation may have been 20° or 30° broad from north to south, generally appears no broader than 4° or 5°, or even than 2° or 3° in some cases*. It is the regular southward progress of the meteor that gives opportunity for the determination of the depth and thickness of the spaces filled with streamers. When the meteor is considerably to the north, its depth is more or less directly seen; when in the plane of the dip, its thickness from north to south is seen; and when in that station, also,

* For a long time, I had not observed zones, in the plane of the dip, broader than about the measures here stated; but in later years I have witnessed some very considerably broader. These are, however, not of frequent occurrence, and present a like arrangement and progress with the narrower zones.

its progress southwards is seen to be occasioned by the extinction of streamers at its northern face, and the formation of new ones at the southern face; and when it proceeds further south than the plane of the dip, its depth comes again more or less directly into view. It is obvious that the stereometric spaces thus filled with streamers, when of considerable length from east to west, necessarily present to the eye the appearance of arches of light; but the peculiar direction of the streamers gives to the arch, when in the plane of the dip, a very different aspect from what it has in a more northerly or southerly position. I have so frequently seen the northerly arch pass into the plane of the magnetic dip, and assume there a very different appearance, as to leave no room for the suggestion in the "Instructions" of the British Association, that the arches in the two positions may be of different origin.

We are now prepared to make some observations on M. Arago's reference to "luminous columns projected from different points of the arch." Such an appearance is often seen, that is, luminous columns *seeming* to spring out of a lower and regular arch; but it is only seeming; for the columns belong to another arch composed of fewer streamers, more near the place of the observer, and therefore seen at a higher angle of elevation. This is discovered when both the appearances come southward towards the plane of the magnetic dip. Then the columns are seen to be advanced southward of the arch; and there is observed an interval, frequently a wide one, clear of lights, between the two appearances. The space occupied by the *columns* (*streamers*) may become more densely crowded with additional streamers in its onward progress, in which case it will become a well-defined arch, before it reach the plane of the dip; or the streamers may not increase in number, yet, when it gets into that plane, it will be seen as one of those feebly lighted belts composed of few streamers which I have recently described. I have so frequently seen one or other of these results, in the case of columns *seeming* to project from a lower arch, as to leave no doubt that the appearance was an optical illusion, and that the columns were much nearer the eye than the arch.

I trust it will be admitted, that we are now able to decide, under what conditions of its appearance, we shall effect a satisfactory geometrical measurement of the height of the aurora above the earth. No measurement of this kind, it is obvious, can be obtained, as M. Arago justly observes in the passage I have referred to, by taking elevations of the centre of the cupola, or corona, when the meteor is in the plane of the magnetic dip. When the meteor is there, each observer sees a centre peculiar to his own station, and which is in the line of the upper prolongation of the dipping needle; just as in a row of persons placed under the key-stones of a bridge of masonry, each one sees a joint of the masonry vertical to himself, and different from the joints over the others. But, as in the case of the bridge, when we remove ourselves quite from beneath it, and to some distance from it, we can then easily determine the height of either the upper or lower parts of the key-stones, by means of a combination of parallaxes, so we may in like manner measure the height of an arch, or

fringe, of aurora, which is placed considerably to the northward or southward of the stations we may select for determining the elevations.

But in the case of the aurora there are serious impediments to the process, in the generally fitful unsteadiness of the object, and equally fitful irregularity of its edges. To avoid the latter inconvenience, the British Association direct the angles of elevation to be taken at the lower edge of the arch (which, it is said, is always best defined) at its summit. I have not observed this edge better defined than the other, excepting on the occurrence of a dark mass under the luminous space, which sometimes takes place, as stated in the instructions. On such occasions, however, the lower edge of the luminous space is always comparatively low, and therefore no clear parallax could be obtained from two stations, unless they were very remote from each other. Besides, the dark mass and defined lower edge are of rare occurrence here, not having been seen for several years.

I have observed already, that in very calm weather the upper edge of the arches is sometimes well-defined; and as that edge, generally, in the arch which first appears here in the evening, is clear from interference with subsequent arches, which for the most part appear only under it, I made preparation for taking elevations of such an arch from two stations, by obtaining the favour of the Rev. Hugh M'Connach, the schoolmaster of this parish, to make the observations at one of the stations.

The stations were chosen with reference to the aurora being probably immediately over the Coreen hills, as indicated by Mr. Minto's observations. The Manse here answers, in this view, for one station, being by measurement 15,700 and 12,500 feet distant from the two nearest elevated summits of the hills respectively; the nearest of the two being almost on its magnetic meridian. The other station could not be placed at a sufficient distance on the north side of the Manse for the river Don intervening. It was therefore placed at Hillhead of Kingsford, on the magnetic meridian of the Manse, and 6810 feet distant from it towards the south. A further extension of the base line in this direction was prevented by a rapid descent of ground, a little beyond the south station, which would have placed the observer out of sight of the Coreen hills. Besides, it was considered inexpedient to have the stations more remote from each other, as it seemed very desirable for the observers to meet before commencing their operations, that they might, on trial, discover how nearly they would agree in taking the elevation of the vertex of the arch of the aurora, an object, in the most favourable case that they could anticipate, somewhat undefined.

After having looked out a considerable time for a proper display of the meteor, and allowed many to pass which had not the requisite conditions, at length, on the 20th of December, 1838, a little after 6 P.M., a very low complete arch, having a well-defined and regular upper edge, presented itself over the Coreen hills. There was a dead calm at the time, with a clear sky; thermometer 39° Fahr. The arch rose slowly upwards, becoming more bright, and promising to be of some continuance. Mr. M'Connach and I met soon after its appearance; and on repeated trials with two

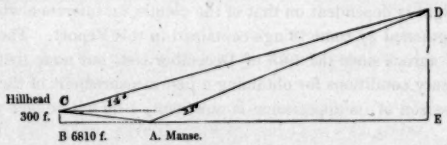
small quadrants with plummets, attached to poles for fixing in the ground, found we agreed in determining the angle of elevation of the vertex of the upper edge of the arch within the limits of half a degree. We then adjusted our watches to the same time; and Mr. M'Connach went with an assistant to Hillhead of Kingsford, to take elevations at every five minutes by the watch, while I remained at the Manse, to take elevations contemporaneously with his, and notice and describe the appearances of the aurora.

It may be best to give a brief account of the successive appearances of the arch, and of those of the contemporaneous phenomena, before presenting the measures of its elevations. When first seen, its lower edge was not yet above the northern hills; but at half-past six o'clock it was quite clear of the horizon at its vertex, and at that point was about 9° broad. The light at this time was nebulous, and equally clear in all its parts, with no certain display of streamers. The upper edge vanished off from the brightest light within the limits of rather less than a degree. At the lower edge the vanishing off was considerably broader. At $6^h\ 35^m$ P.M. a brilliant display of streamers suddenly appeared over Callievar, a detached mountain three miles due west of the Manse, somewhat higher than any part of the Coreen hills; and over that mountain a solitary dense cloud was formed, two or three minutes after the appearance of the streamers there. These phenomena were quite disjoined from the arch, which in the mean time rose gradually higher above the horizon, and in place of the nebulous light began to exhibit, especially near the vertex, streamers or pencils of rays pointing upwards. These were not very brilliant, but quite defined. At $6^h\ 40^m$, a few detached very brilliant streamers, whose lower ends were concealed by the hills, appeared under the arch a little to the eastward of its vertex. These seemed to flit with great velocity from west to east, and from east to west, and appeared and disappeared in quick succession for about the space of five minutes. Their upper ends passed the lower edge of the arch, but never extended so high as the upper edge. When they disappeared the lower edge presented the same regularity and gradual vanishing off of the light as before their appearance. At 7^h P.M. the play of streamers across the arch had become somewhat more brilliant; and its edges remained equally even and well-defined as at the earlier periods, the upper one still maintaining its superiority over the lower in that respect. The arch was at this time about 12° broad; and a few very small clouds appeared in its west end, concealing the light at their places, but the edges were clear. At $7^h\ 5^m$, although the clouds had increased in number, they formed no impediment to the determination of the elevations; but by $7^h\ 10^m$ the whole sky had become too much obscured to admit of longer continued contemporaneous observations. At $7^h\ 25^m$ an opening in the clouds permitted the vertex of the arch to be seen, at the Manse, when it was observed to be still regular in its edges, and to have become of higher elevation.

Observed Angular Elevations of the vertex at the upper edge of an arch of aurora borealis, by the Rev. James Farquharson, at Manse of Alford, and contemporaneously by the Rev. Hugh M'Connach, at Hillhead of Kingsford, on the same magnetic meridian with Manse of Alford, distant from it in a southerly direction 6810 feet, and about 300 feet higher in level.

	At Manse of Alford. Angle of elevation.	At Hillhead of Kingsford. Angle of elevation.
At 6^h 45^m P.M.	16°	
6 50	$17\frac{1}{2}$	
6 55	19	
*7 0	21	14°
7 5	22	15
7 10	arch obscured by clouds at both stations.	
7 25	28°	seen only at Manse of Alford.

In making out the calculations of the height from these data, it is obvious that we may disregard the corrections for the rotundity of the earth, the difference of refraction at the two stations, and the difference of the horizontal and inclined distances of the stations, as they are all within the limits of the effect of the probable errors in observing a somewhat undefined object like the edge of the arch. But there is a considerable correction to be made in the angle observed at the Hillhead of Kingsford station, arising from its height above the level of Manse of Alford. Several years ago I had occasion to determine this, and found it about 300 feet by the barometer. This correction and the mode of calculation will become evident by means of the following diagram, which represents the first contemporaneous observations at seven o'clock.



Calculating from these data, we have the height D E = 5693 feet.

Thus the height of the upper edge of the aurora was 5693 feet above the level of the Manse of Alford. The vertex of the arch is found from these observations to have been 14831 feet northward of the same place, that is, over the nearest summits of the Coreen hills, two of which, it has been stated, are respectively 12500 and 15700 feet distant in the same direction. The most continuously elevated ridge of the same hills is about two miles farther north, and it was probably over it that the arch had its commencement.

At the time of the contemporaneous observations, whose results are given, the

* Mr. M'Connach did not reach Hillhead of Kingsford to get observations before seven o'clock.

arch was 12° broad. This gives by calculation 3212 feet for the vertical extension of the fringe of streamers, and leaves 2481 feet for the height of the lower edge above the level of Alford. The tops of the Coreen hills are about 1000 feet higher than that level; and thus the lower edge of the arch, whose elevation was measured, was only about 1500 feet above these hills at their highest points.

The result of this measurement agrees sufficiently with that of incidentally contemporaneous observations made by the Rev. James Paull of Tullynessle and me, on the 20th of December, 1829, as reported by me in a communication to the Royal Society, honoured with a place in the Philosophical Transactions of 1830*, and by which it appeared the aurora of that evening was within the limits of 4000 feet above the earth. These observations, although not made with instruments, were too decisive in all their conditions of the length of base line, clearness of parallax, and certainty that we had both seen the same phenomenon, to admit of doubt of the very limited elevation above the earth. The result agrees also with the ingenious observation of Mr. Minto, and with that which might have been considered decisive of the question, namely, the observation of Captain Parry and Lieutenants Sherer and Ross, on the 27th of January, 1825, of the light of the aurora coming between them and a neighbouring height.

James Farquharson.

Alford, May 13, 1839.

P.S. I delayed making this Report, in expectation of finding other opportunities of making similar measurements, with the view of determining the variations of height to which the aurora is liable. My former communications upon the subject went to show that the height is dependent on that of the clouds, an inference which it will be observed is strengthened by some things contained in this Report. There have been many displays of aurora since the 20th of December last, but none that I have seen having the necessary conditions for obtaining a just measurement of the height; and as the ordinary season of its appearance is now over, I do not longer withhold the Report.

* pp. 104, 105, 106.

XVII. *On the Constitution of the Resins. Part II.* By JAMES F. W. JOHNSTON, *Esq. M.A., F.R.S., Professor of Chemistry and Mineralogy in the University of Durham.*

Received May 9,—Read June 20, 1839.

III. *The Resin of Gamboge, or Gummi Gutt.*

THE medical and commercial values of the several varieties of gamboge which occur as articles of commerce in the European markets, and their botanical origin, have lately been investigated by Dr. CHRISTISON*. He found the different varieties to contain respectively

	Siam.		Ceylon.	
	Pipe.	Cake.	1.	2.
Resin	72·2	64·8	70·2	75·5
Cerabin	23·0	20·2	19·6	18·3
Cerasin	.....	.....	.....	0·7
Fecula	.....	5·6	.....	.....
Woody fibre, &c.	.....	5·3	5·6	.....
Moisture	4·8	4·1	4·6	4·8
	100	100	100	99·3

The resin of gamboge is soluble in alcohol, and largely in ether; and so far as experiments go may be obtained by either solvent free from the foreign substances with which it is mixed in the resin of commerce. Like many of the other resins, acid as well as basic, it retains with considerable obstinacy the last traces of these solvents, and requires the prolonged action of a temperature above that of complete fusion fully to expel them.

1. 5·32 grains of the resin precipitated by water from its solution in alcohol, dried and fused at 212° FAHR., gave $\ddot{C} = 13{\cdot}98$, and $\dot{H} = 3{\cdot}52$ grains.

2. 6·685 grains of the same gave $\ddot{C} = 17{\cdot}64$, and $\dot{H} = 4{\cdot}43$ grains.

3. 7·675 grains of the resin obtained by evaporating the ethereal solution and prolonged heating, gave $\ddot{C} = 20{\cdot}060$, and $\dot{H} = 5{\cdot}04$ grains.

4. 8·235 grains of the same heated to 350° FAHR., gave $\ddot{C} = 21{\cdot}640$, and $\dot{H} = 5{\cdot}365$ grains.

5. To be certain that alcohol and ether were absent, the resin was dissolved in caustic potash, precipitated by muriatic acid, washed, dried, and fused at 350° FAHR. In this state it fused less readily, and was of a darker colour.

13·146 grains gave $\ddot{C} = 34{\cdot}432$, and $\dot{H} = 8{\cdot}67$ grains.

* Proceedings of the Royal Society of Edinburgh, March 7, 1836.

These results give per cent. respectively,

	From alcohol.		From ether.		After solution in potash and fusion at 350°.
	Fused at 212°.	Fused at 212°.	Fused at 212°.	Fused at 350°.	
Carbon ..	72·662	72·763	72·280	72·668	72·406
Hydrogen	7·352	7·363	7·296	7·225	7·243
Oxygen ..	19·986	19·874	20·424	20·351	20·351
	100	100	100	100	100

It is difficult to arrive at a satisfactory conclusion in regard to the true formula for this acid resin.

The results of analysis approach exceedingly near to the beautifully simple formula $C_5 H_3 O$, or $C_{40} H_{24} O_8$, which gives

		Calculated.	Experiment.
C_5	= 382·185	= 73·550	72·763
H_3	= 37·438	= 7·205	7·363
O_1	= 100·000	= 19·245	19·874
	519·623	100	100

This formula is further interesting, because of the close relation it would establish between oil of turpentine and its resin, and that of gamboge; since

$$\overset{\text{Oil of turpentine.}}{C_5 H_4 \left\{ \begin{matrix} -H \\ +O \end{matrix} \right.} = C_5 H_3 O.$$

The fact, however, that in all the analyses there is a constant deficiency of carbon to the amount of nearly one per cent., renders the formula suspicious. It is true that the gambodic acid has a strong affinity or attraction for ether and alcohol, and that a certain quantity of these substances may have been present in some of the specimens analysed; yet it would be necessary to suppose a much larger admixture of them than seems possible, in order to account for so great a diminution in the per centage of carbon. Neither can we admit the presence of these substances in the resin after solution in potash, though the carbon in this also is considerably less than the formula requires.

In order to determine whether a still higher temperature than 350° Fahr. would drive off a further portion of alcohol from the resin precipitated from its solution by water, I heated it to 400° + Fahr., when it ceased to emit its agreeable fragrant odour, gave off white vapours, and became slightly darker in colour. In this state 11·38 grains gave $\ddot{C}$ = 30·23, $\dot{H}$ = 6·73 grains, or per cent.,

Carbon	=	73·791
Hydrogen	=	6·601
Oxygen	=	21·608
		100

The carbon here is sufficiently great, but there is much too little hydrogen for the formula ($C_5 H_3 O$), to which this resin seems so closely to approximate.

After fusion at this temperature, however, the gambodic acid was no longer wholly soluble in alcohol, nearly one half of its bulk being left behind in the form of a yellow powder when digested in this liquid. This powder was collected, washed with alcohol, and heated for a long time at 212° + Fahr. previous to analysis. At 400° Fahr. it undergoes no apparent change; at 500° Fahr. it becomes brown, and gradually darkens, but does not melt. 7·30 grains gave $\ddot{C} = 18·93$, and $\dot{H} = 4·62$, or per cent.,

	Experiment.	Calculated.
Carbon	= 71·703	72·033
Hydrogen	= 7·031	6·762
Oxygen	= 21·266	21·205
	100	100

This result agrees with the formula $C_{40} H_{22} O_9$, according to which the second column is calculated.

The formula which most nearly represents the result of experiments on the unchanged resin is $C_{48} H_{29} O_{10}$. This gives

		per cent.
C_{48} =	3668·976 =	72·929
H_{29} =	361·908 =	7·193
O_{10} =	1000·000 =	19·878
	5030·884	100·000

in which there is an allowance for loss of carbon and for a similar slight excess of hydrogen in the results of analysis, being the directions in which errors are likely to occur.

It is satisfactorily ascertained, however, that the gamboge of commerce, as we have found reason to conclude is the case with dragon's blood, undergoes a process of manufacture before it is brought to market. Like the reed dragon's blood, it has all the appearance of having been fused and moulded into shapes; the effect of such fusion in the case of the red resin is, as we have seen*, to diminish the amount of carbon about one per cent., and if we suppose a similar change produced on the gamboge, the deficiency of carbon in the analysis will be sufficiently accounted for. The likelihood of an analogous change in the two resins is the greater, as they belong apparently to a kindred group, the several members of which are related almost as closely as mastic and colophony. On comparing the quantity of hydrogen found by analysis with that given by the formula $C_{40} H_{24} O_8$, 7·205 per cent., we find them approach so closely as scarcely to allow for the necessary errors of experiment, but in the reed dragon's blood there was a similar deficiency, so that until we have the opportunity of analysing the gamboge resin as it issues from the tree, we might adopt the formula to which the results appear to point. There is an analogy, however, in favour of the formula

* See page 134 of the present volume.

$C_{40}\ H_{23}\ O_8$ containing one equivalent less of hydrogen, which is not unworthy of attention. When heated above 400° Fahr. we have seen that this resin is partly changed into a nearly insoluble resin $= C_{40}\ H_{22}\ O_9$, that is

$$C_{40}\ H_{23}\ O_8 \begin{cases} -H \\ +O \end{cases}.$$

In like manner mastic resin when so heated is in part changed into $C_{40}\ H_{30}\ O_5$, that is

$$C_{40}\ H_{31}\ O_4 \begin{cases} -H \\ +O \end{cases}.$$

It is reasonable to suppose that the nature of the change which takes place is the same in both; and though I do not consider, notwithstanding the precautions adopted, that the number of atoms of hydrogen in any of the formulæ I have given for the resins can be considered *absolutely certain*, yet there being a reasonable probability that mastic resin A, is represented by $C_{40}\ H_{31}\ O_4$, there is reason from the present analogy to infer that gamboge resin is $C_{40}\ H_{23}\ O_8$.

One interesting and important fact may be considered as established, whichever of these formulæ be adopted, that a small change in the number of atoms of hydrogen only, may give birth to new resins possessed of very different properties. We have for example,

Colophony $= C_{40}\ H_{30}\ O_4$ Liebig.
Mastic A. $= C_{40}\ H_{31}\ O_4$

represented generally by

$$C_{40}\ H_{32-x}\ O_4$$

the resin of which

$C_{40}\ H_{32}\ O_4$ is the formula, being undetermined.

And we have also

Resin of dragon's blood $= C_{40}\ H_{21}\ O_8$
Resin of gamboge . . . . $= C_{40}\ H_{23}\ O_8$?

And the general formula

$$C_{40}\ H_{24-x}\ O_8$$

may represent a second large group, of which, as in the former, only two members are as yet determined.

In the present stage of our inquiry it would be premature to dwell on theoretical indications as to what we may hereafter expect to meet with, but it may be remarked that H_{32} and H_{24} seem to point to a series, of which H_{64}, H_{16} and H_8 are members, and which may respectively form the starting-points as it were, of new groups.

Salts of Gambodic Acid.

Gambodiates of Potash and Soda.—The salts of the alkaline metals may be formed by dissolving or digesting the acid in solutions of the caustic alkalies. In strong solutions the salt is very sparingly soluble, so that by digesting the acid in such solution, the compounds may easily be obtained in a solid state. In colour they are some-

what darker than the pure resin, and very soluble in pure water, giving reddish-brown solutions, and though more sparingly, yet still largely soluble in alcohol. They are decomposed by the dilute mineral acids, which precipitate the acid from its saline solutions unchanged, and in the form of a pale-yellow bulky powder.

Gambodiate of Ammonia.—Gambodic acid dissolves slowly in dilute caustic ammonia, giving a brownish-red solution. The solution is most readily obtained by adding caustic ammonia to the alcoholic solution of the acid, diluting largely with water and distilling or boiling off the alcohol and excess of ammonia. Evaporated to dryness at a temperature below 212° FAHR., it leaves a brittle resinous mass having the colour of the acid. Instead of the fragrant smell of the resin, however, it has assumed a faint unpleasant animal odour. It is insoluble in pure water, but dissolves on the addition of a little caustic ammonia. It dissolves also in alcohol, and is decomposed by the mineral acids. Boiled in a solution of caustic potash, ammonia is evolved and a salt of potash formed. Its solution in water precipitates the ammonia nitrate of silver and the ammonia acetate of lead (PAYEN'S salt) of a yellow colour, and the ammonia sulphate of copper of a dark-reddish-brown.

Earthy and Metallic Salts.—On these salts I have made many experiments with results in some cases sufficiently discordant, and which led me at first to consider that the equivalent of this resin should be represented by ($C_{50}H_{29}O_{10}$), instead of ($C_{40}H_{23}O_8$), as the analysis of the resin appears to indicate. I am now inclined, however, to adopt the formula containing C_{40}, as entering into the expression for the gambodiates, and to attribute the observed differences between experiment and calculation to the difficulty of obtaining these as well as other resinous compounds in a perfectly pure state, especially free from mutual admixture. To this conclusion I am further led by the study of the salts of mastic resin A, of which an account has already been given.

Properties of the Earthy and Metallic Gambodiates.—1. When fresh prepared from alcoholic solutions these salts are yellow, slightly soluble in alcohol, and insoluble in water. When first precipitated from solutions of chloride of calcium and nitrate of strontia, by means of ammonia, they are of a beautiful red, but by standing they subside yellow. Precipitated from ammoniacal *aqueous* solutions, they are brownish or brownish-red.

2. Collected on the filter after precipitation from alcoholic solutions, washed with alcohol, and dried by pressure on bibulous paper, they are in the form of a beautiful yellow powder, in which state they remain, if dried by a very gentle heat in the open air, raised after a sufficient time to 212° FAHR. If immediately on being dried by pressure as much as possible between folds of paper, they are exposed to a heat of upwards of 100° FAHR., they melt, and run into a thin liquid, which on cooling solidifies into a red brittle resin, giving a yellow powder. This property, which is common to these with the salts of many other resins, appears to indicate a combination of the salts with alcohol, from the last portions of which, like the resins themselves, they

are with difficulty separated. They may be heated, however, to 350° or 400° FAHR., without decomposition, emitting only the fragrant odour characteristic of the gambodic acid itself. At or under this temperature they melt, those of the earths excepted, and on cooling assume the appearance of a reddish-brown resin, not unlike the acid, and like it giving a beautiful yellow powder. At a higher temperature they are decomposed, giving off empyreumatic products. The salt of silver is discoloured by exposure to the air, and when dry is of a dirty-dark-green. They are all decomposed by boiling in acetic and dilute nitric acids.

I had spent much time in preparing these salts by means of alcoholic solutions, before I discovered that the resin possesses a property which enables us to prepare very many of its salts from aqueous solutions. The gambodiate of ammonia being soluble in dilute ammonia, and *not* precipitable by water, it is sufficient to add caustic ammonia to an alcoholic solution of the resin, and to dilute with water, when the addition of an ammoniacal solution of magnesia, oxide of manganese, oxide of copper, oxide of zinc, acetate of lead, or of any other oxide soluble in caustic ammonia, causes a precipitate of the corresponding gambodiate of a brownish-red colour. By washing with dilute ammonia these may be obtained in a state of comparative purity*. Analogous compounds may be formed by adding an alcoholic solution of the resin to similar solutions of the metallic salts with or without the addition of ammonia.

A. *Salts of Lead.*—1. When a solution of the resin in alcohol is mixed with one of acetate of lead, a yellow precipitate falls. Washed with alcohol and dried

				per cent.
a. At	212° FAHR.,	11·425 grs. gave	2·224 oxide of lead	= 19·466
b. After fusion, at	370° FAHR.,	13·03 grs. gave	2·58 oxide of lead	= 19·80

A second portion thrown down from a solution in which a large excess of resin was present gave only 17·36 per cent. of oxide. A *sesquisalt* = 3 (C_{40} H_{23} O_8) + 2 Pb O, contains 18·32 per cent. of oxide, and it will be recollected that mastic resin A. in similar circumstances gave also a sesquisalt†.

2. To the mixed solutions as above, after the precipitate was separated, caustic ammonia was added with agitation. The new precipitate was also yellow, but when washed and dried 14·74 grs. gave only 2·046, or 13·88 per cent. of oxide of lead. This agrees with the formula Pb O + 2 (C_{40} H_{23} O_8) which contains 14·40 per cent. of oxide, though it is not easy to understand why a *bi*salt should be thrown down when the solution is rendered more neutral by the addition of ammonia.

3. An ammoniacal solution of the resin was diluted with water, and a solution of PAYEN's ammoniacal subacetate of lead was added to it. A yellow precipitate fell which was collected, carefully washed, and dried at 212° FAHR. At a low heat it took fire and burned like tinder, without melting.

* This property renders gamboge of great value for experimental illustration of the properties of the resins in the Class-room.

† Vid. ante, p. 124.

10·733 grs. left 5·284 grs. of oxide of lead = 49·231 per cent. This indicates three of base to one of acid; the formula $3\,PbO + (C_{40}H_{23}O_8)$ requiring 50·23 per cent.; and this tribasic salt is precisely the analogue of the *tribasic* acetate from which it is formed.

After being digested in acetic acid, and again washed and dried, this salt lost five-sixths of its base, becoming a *bi*salt. Thus 11·066 grains left 1·635 of oxide of lead = 14·777 per cent.; the formula, as already stated, requiring 14·40 per cent. That an acid salt should be formed under these circumstances is what we should expect; but whether a *bi*salt is the constant result I have not determined.

B. *Salts of Copper.*—1. A dilute ammoniacal solution of the resin in water was mixed with one of ammoniaco-sulphate of copper; a brownish-yellow precipitate fell, which was washed with dilute ammonia, and dried at 212° Fahr.

11·037 burned in the air left 1·197 $\dot{C}u$ = 10·845 per cent.
13·455 of another portion left 1·40 $\dot{C}u$ = 10·405 per cent.

A portion of the dry salt, after boiling in dilute ammonia, still left 10·994 per cent. of oxide.

These results indicate a neutral salt, the formula $\dot{C}u + (C_{40}H_{23}O_8)$ requiring 10·68 per cent. of oxide of copper*.

2. A further portion of the salt was prepared by adding the ammoniacal resin to a solution of common sulphate of copper; and, as this might contain excess of oxide, one portion of it was digested while moist in *hot* dilute ammonia. When dried it left in two experiments 18·951 and 18·830 of oxide per cent. respectively. Another portion was boiled in strong caustic ammonia, by which, as appeared from the colour of the solution, a portion of the acid was taken up. Washed, dried, and burned, it left 14·666 per cent. of oxide of copper.

The former result agrees with $2\,\dot{C}u + (C_{40}H_{23}O_8)$, which requires 19·31 per cent. of oxide.

The latter agrees with $3\,\dot{C}u + 2\,(C_{40}H_{23}O_8)$, which requires 15·21 per cent. of oxide.

It is impossible, however, without several repetitions of these experiments, to say that these coincidences are more than accidental, though from analogy it appears probable that such compounds do exist. Above all, their true nature can only be known by the ultimate analysis of the salts,—a work of great labour, but which I do not despair of being able to undertake. By varying the mode of preparation I obtained a copper salt by direct precipitation, containing 14·824 per cent. of oxide, agreeing with one of those just described. But if the three classes of salts above obtained be constant and definite, the circumstances under which they may be formed without failure requires further study.

C. *Salts of Zinc.*—The gambodiate of zinc is obtained by mixing the ammoniacal

* The equivalent of oxide of copper being 495·695.

resin with a solution of zinc in ammonia, or with an ammoniacal solution of sulphate of zinc. It is of a brownish-yellow colour. If the solution be too largely diluted with water, an excess of oxide of zinc is apt to be thrown down along with the salt. Thus the first portion I prepared gave me 14·17 per cent. of oxide of zinc, while another prepared with more care gave me in two experiments 11·242 and 10·976 per cent. respectively. A neutral salt = $Zn\,O + (C_{40}\,H_{23}\,O_8)$, contains 10·83 per cent. oxide of zinc.

D. *Salts of Lime, Strontia, and Magnesia.*—*a.* To alcoholic solutions of chloride of calcium and of nitrate of strontia, ammonia was added, and afterwards a solution of gambodic acid in alcohol. The former gave an abundant, the latter a very sparing precipitate. The mixed solutions at first became of a beautiful red colour, but the precipitate, as it fell, gradually assumed a more yellow shade. Washed without access of air, and dried at 360°, the lime salt gave in two experiments 6·119 and 6·192 per cent. of lime; the strontia salt gave 9·877 per cent. of strontia.

If these results are to be depended upon, they indicate a *sesqui*salt in both cases; since

$$\dot{C}a + 1\tfrac{1}{2}\,(C_{40}\,H_{23}\,O_8) \text{ contains } 5{\cdot}72 \text{ per cent. of lime,}$$

and

$$\dot{S}r + 1\tfrac{1}{2}\,(C_{40}\,H_{23}\,O_8) \text{ contains } 9{\cdot}43 \text{ per cent. of strontia.}$$

b. The ammoniacal resin in water gives, with ammoniacal sulphate of magnesia, a copious precipitate, which, dried and burned, yielded 4·542 and 4·681 per cent. of magnesia, which, however, is not reconcileable to any formula.

E. *Salts of Silver.*—1. Newly precipitated oxide of silver, digested in gambodic acid in alcohol, gave a dark-brown salt, which fused at 360° Fahr; and of which, when burned, 20·335 grains left 5·46 of silver = 28·762 per cent. of oxide. A neutral salt, $Ag\,O + (C_{40}\,H_{23}\,O_8)$, contains 25·94 per cent., to which the salt above obtained approximates. It will be readily understood that very careful agitation would be required to bring all the particles of the oxide introduced in the state of powder into contact with the resin held in solution, and that an excess of silver is to be expected in a salt prepared by such a process.

2. When an alcoholic solution of the resin is poured into a similar solution of nitrate of silver, no precipitate falls; but if the mixture be allowed to stand for some time, the inside of the glass vessel becomes covered with a coating of metallic silver, and a small quantity of a black powder gradually falls to the bottom. The same effect follows if the resin of dragon's blood be used, and in a still more marked manner with the pure resin of guaiacum. If ammonia be added, a yellow precipitate falls, which is speedily discoloured by the air, and ultimately becomes dark-green. Carefully dried,

6·94 grains left 1·00 grain of silver = 15·475 per cent. of oxide of silver.
7·766 grains left 1·146 grains of silver = 15·848 per cent. of oxide of silver.

These results indicate the formation, as was the case with mastic resin A*, of a *bi*-salt, containing also, like the salt of that resin, a small excess of silver. The formula $Ag\,O + 2\,(C_{40}\,H_{23}\,O_8)$ requires 14·90 per cent. of oxide of silver.

3. Into an aqueous solution of ammonia nitrate of silver, an ammoniacal solution of gambodic acid was slowly poured with agitation, a yellow precipitate began to fall, which re-dissolved on a further addition of the resin, and was again thrown down on adding ammoniacal nitrate of silver. The yellow precipitate gradually collected into brown flocks, and formed a brown coherent sediment, leaving the supernatant liquid of a pale yellow colour. The precipitate was well washed with distilled water, collected on the filter, and dried at 250° Fahr., till at that temperature it ceased to soften.

13·17 grains burned in the air left 1·17 of metallic silver, or 9·54 per cent. of oxide.

7·866 grains left 0·725 of silver = 9·90 per cent. of oxide.

A salt consisting of three equivalents of acid to one of base, or $Ag\,O + 3\,(C_{40}\,H_{23}\,O_8)$, contains 10·22 of oxide of silver. We may safely consider the compound prepared by this method, therefore, as a *ter*salt, the excess of ammonia present probably retaining the silver in solution, so as to prevent its forming a more basic combination. It is not unlikely that by varying the process a *bi*salt might be obtained from aqueous solutions similar to that which was given by alcoholic solutions.

Constitution of the Salts of Gambodic Acid.

Of the salts above described I have subjected to ultimate analysis only the *bi*salt of silver, obtained by mixing the alcoholic solutions of the resin and of nitrate of silver, and adding ammonia. This salt contained 15·88 per cent. of oxide of silver, and when burned with oxide of copper,

$$8{\cdot}19 \text{ grains gave } \ddot{C} = 18{\cdot}02, \text{ and } \dot{H} = 4{\cdot}47.$$
$$7{\cdot}60 \text{ grains gave } \ddot{C} = 16{\cdot}875, \text{ and } \dot{H} = 4{\cdot}11.$$

These results are equal to

	A.	B.	Calculated.
Carbon	= 60·954	= 61·40	61·51
Hydrogen	= 6·065	= 6·00	5·77
Oxygen	= 17·098	= 16·72	17·82
Oxide of silver	= 15·883	= 15·88	14·90
	100	100	100

The numbers in the third column are calculated according to the formula $Ag\,O + 2\,(C_{40}\,H_{23}\,O_8)$, and to these numbers the experimental results approximate very closely. Like the similar analyses of the salts of mastic resin A†, these show that in combining with oxides the gambodic acid does not part with the elements of water. They are opposed, however, to the view suggested by the constitution of some of the salts of

* Ante, p. 126. † Ante, p. 128.

that resin, that the metal replaces an equal number of equivalents of hydrogen when it combines with the resin; and they support rather the other view, which would represent the normal state of the acid resin to be that in which it exists when in a state of combination, and that the hydrogen contained in their salts of the metallic oxides is the true quantity which enters into the composition of these bodies.

Conclusions.—From the preceding investigation it appears,

1. That the most probable formula for gamboge resin is $C_{40}\ H_{23}\ O_8$, though all the specimens analysed yield too little carbon by nearly one per cent. This deficiency is supposed to be due to a change produced during the preparation of the natural resin for the market.

2. When heated to about 400° Fahr. it undergoes partial decomposition, a resin soluble in cold alcohol being formed, and another insoluble in that liquid. The constitution of the latter seems to be represented by $C_{40}\ H_{22}\ O_9$.

3. It forms with the metallic oxides numerous classes of salts, the existence and constitution of which the preceding experiments must be considered as only rendering *probable*. A complete study of the resinous salts, and of the circumstances under which the several classes of them are necessarily formed, though it would involve much labour, would probably lead to interesting results. The various saline compounds obtained as above described may be classed as follows, representing the formula $C_{40}\ H_{23}\ O_8$ by $\overset{r}{G}$.

	Formula.	Oxide per cent.		How obtained.
		Found.	Calculated.	
1. *Tersalts* ...	$AgO + 3\overset{r}{G}$	9·90	10·22	By mixing ammoniacal aqueous solutions.
2. *Bisalts* ...	AgO	15·47	14·90	Mixing alcoholic solutions and adding ammonia.
	$PbO + 2\overset{r}{G}$	14·77	14·40	By digesting in dilute acetic acid, the salt precipitated on mixing ammoniacal aqueous solutions.
3. *Sesquisalts*	$2\,PbO + 3\overset{r}{G}$	19·46	18·32	Mixing the resin in alcohol with acetate of lead in alcohol.
	$2\,CaO + 3\overset{r}{G}$	6·119	5·72	Mixing the resin with chloride of calcium in alcohol, and adding ammonia.
	$2\,SrO + 3\overset{r}{G}$	9·87	9·43	Mixing the resin with nitrate of strontia in alcohol, and adding ammonia.
4. *Neutral* ...	$AgO + \overset{r}{G}$	28·76	25·94	Digesting the resin on fresh precipitated oxide of silver.
	$CuO + \overset{r}{G}$	10·84	10·68	From ammoniacal sulphate of copper by resin in dilute ammonia.
	$ZnO + \overset{r}{G}$	10·97	10·83	From ammoniacal sulphate of zinc by resin in dilute ammonia.
5. *Subsesqui*	$3\,CuO + 2\overset{r}{G}$	14·66	15·21	Boiling the fresh precipitated $CuO + \overset{r}{G}$ in concentrated caustic ammonia.
6. *Disalts* ...	$2\,CuO + \overset{r}{G}$	18·95	19·31	Digesting do. in hot dilute caustic ammonia.
7. *Tribasic* ...	$3\,PbO + \overset{r}{G}$	49·23	50·23	Mixing ammonia acetate of lead (tribasic) with the resin in dilute caustic ammonia.

I cannot persuade myself to regard this formidable list of salts without suspicion, especially as several of them have been formed only once. In detailing my results and observations, however, I have in some measure cleared the way for future inquirers.

IV. *Resin of Guaiacum.*

When the resin of guaiacum of the shops is treated with alcohol in the cold it is nearly all dissolved, giving a dark-brown solution. On evaporating this solution in a flat dish, and heating it for twelve hours at a temperature rising from 180° to about 250° Fahr., a very beautiful transparent ruby-coloured resin is obtained, brittle and electric, melting at 212° Fahr., and emitting an agreeable fragrant odour.

Of this resin thus carefully dried,

A. 10·647 grs. gave $\ddot{C} = 27{\cdot}167$ and $\dot{H} = 6{\cdot}585$

B. 10·995 grs. gave $\ddot{C} = 27{\cdot}975$ and $\dot{H} = 6{\cdot}733$

these results gave per cent.

	A.	B.
Carbon . =	70·555	70·35
Hydrogen =	6·870	6·80
Oxygen . =	22·575	22·85
	100	100

and they correspond most closely with the formula $C_{40}\,H_{23}\,O_{10}$ which gives

40 Carbon . =	305·75 =	70·37
23 Hydrogen =	28·70 =	6·60
10 Oxygen . =	100·00 =	23·02
	434·45	100

This resin in a natural arrangement, therefore, must stand in the same group with the resins of dragon's blood and of gamboge, which as we have already seen may be represented by

Resin of dragon's blood $C_{40}\,H_{21}\,O_8$
Resin of gamboge . . . $C_{40}\,H_{23}\,O_8$
Resin of guaiacum . . $C_{40}\,H_{23}\,O_{10}$

Salts of Guaiacum Resin.—When the solution of this resin in alcohol is added to an alcoholic solution of acetate of lead in excess, a white precipitate falls, which becomes blue on exposure to the sun's rays*. After separating the precipitate, ammonia throws down a further portion from the supernatant liquid. I have analysed three successive portions of the first of these compounds, which contains two equivalents of oxide of lead to forty of carbon; but the results are so little concordant with the analysis of the uncombined resin as to render further investigation necessary.

With nitrate of silver this resin gives no precipitate, but on standing exposed to the light, the silver, in considerable quantity, is thrown down in the metallic state. I have not examined what change of composition the resin undergoes during this deoxidation of the metal.

* A delicate photogenic paper may be formed by first washing with an alcoholic solution of guaiacum resin, and afterwards with one of neutral acetate of lead.

V. *Acaroid Resin.* (*Botany Bay Resin, Yellow Gum.*)

This resin exudes from the *Xanthorrhœa hastilis,* is of a darker reddish yellow colour than gamboge, comes to this country generally mixed with the spines and bark of the tree, gives in alcohol and ether a much darker solution than gamboge, and a darker resin when evaporated. It emits also a peculiar fragrant odour when melted, and differs further from gamboge in being almost entirely precipitated by water from its solution in alcohol, even when much ammonia has been added. Dried in a thin film at 250° Fahr. for twelve hours,

A. 11·655 grs. gave $\ddot{C} = 28·523$ and $\dot{H} = 6·036$
B. 11·61 grs. gave $\dot{H} = 6·048$

and of another portion similarly heated

C. 10·236 grs. gave $\ddot{C} = 25·204$ and $\dot{H} = 5·258$

	A.	B.	C.
Carbon . =	67·67		68·085
Hydrogen =	5·75	5·78	5·707
Oxygen . =	26·58		26·208
	100		100

And they indicate the formula $C_{40}\ H_{20}\ O_{12}$ which by calculation gives

40 Carbon . =	3057·480 =	67·84
20 Hydrogen =	249·592 =	5·54
12 Oxygen =	1200·000 =	26·62
		100

The slight excess of carbon in analysis C is no doubt an error of experiment.

This resin, therefore, belongs also to the group represented by the general expression $C_{40}\ H_{24-x}\ Oy$, and it contains more oxygen than any other resinous substance hitherto analysed.

General Remark.—In so far as we are entitled to draw general conclusions from the analyses contained in this and the preceding paper, it appears,

1. That *many* of the resins may be represented by formulæ exhibiting their elementary constitution, and the weight of their equivalents in which 40 C is a constant quantity.

2. That there appear to be groups in which the equivalents both of the carbon and the hydrogen are constant, the oxygen only varying, and others in which the hydrogen alone varies, the two other elements being constant.

In a subsequent paper I hope to extend further these first generalizations.

Durham, May 2, 1839.

XVIII. *On the Constitution of the Resins. Part III.* By James F. W. Johnston, *Esq. M.A., F.R.S., Professor of Chemistry and Mineralogy in the University of Durham.*

Received June 11,—Read June 20, 1839.

VI. *Resin of Sandarach.*

THE resin of sandarach dissolves readily in alcohol, giving a yellow solution, which may be obtained of the consistence of a balsam. It dissolves without appreciable residue.

If this solution be largely diluted with alcohol, a white flocky resin separates in small quantity, falls slowly to the bottom, and may be procured in a state of considerable purity by decantation and washing with cold alcohol.

If to the alcoholic solution solid caustic potash, or a concentrated solution of this alkali in water be added, a precipitate falls, which re-dissolves if the potash be present in great excess. By adding, to a solution containing potash in excess, a solution of the resin as long as any precipitate falls, the whole of the resin thus separable may be thrown down. It may be washed by affusions of hot alcohol, by which a portion of it is dissolved; and the alcohol it holds apparently in combination, may be separated by heating for a sufficient length of time at a temperature not exceeding 250° Fahr.

I. *Resin* A. *of Sandarach.*—The white flocks which fall to the bottom of the solution of sandarach resin in alcohol, being collected on the filter, washed with alcohol, and afterwards boiled in water, are obtained in the form of a white powder, having neither taste nor smell. Dried at 212° Fahr. this resin undergoes no change; but if the temperature be raised to about 300° Fahr., it gradually assumes a yellow colour, and slightly coheres, but does not melt. If the heat be still increased, the colour becomes brown, apparently indicating incipient decomposition.

1. Of a portion of the resin thus obtained, and heated till it became yellowish,

A. 11·175 grains gave $\ddot{C} = 31·70$, $\dot{H} = 9·86$.
B. 11·095 grains gave $\ddot{C} = 31·315$, $\dot{H} = 9·818$, or per cent.,

	A.	B.
Carbon	= 78·437	78·043
Hydrogen	= 9·803	9·832
Oxygen	= 11·760	12·125
	100	100

2. Of a portion obtained by the same method from a second quantity of the crude resin, and well washed,

11·802 grains, heated till it acquired a tinge of yellow, gave $\ddot{C} = 33·06$, $\dot{H} = 10·53$, or, per cent.,

Carbon	= 77·456
Hydrogen	= 9·913
Oxygen	= 12·631
	100

This analysis, which only the loss of the remainder of my resin by an accident prevented me from repeating, agrees with the formula $C_{40}\ H_{31}\ O_5$, which gives

		Calculated.	By experiment. First portion.		Second.
40 Carbon	= 3057·480	= 77·515	78·437	78·043	77·456
Hydrogen	= 386·867	= 9·808	9·803	9·832	9·913
Oxgen	= 500·000	= 12·677	11·760	12·125	12·631
	3944·347	100	100	100	100

There can be little doubt, therefore, that the sparingly soluble resin of sandarach contains five of oxygen to forty of carbon; and as more care was taken to purify by washing with alcohol the portion which gave the result in the last column (2.), the true formula is most probably that above given, $C_{40}\ H_{31}\ O_5$.

II. *Resin* B. *of Sandarach.*—The alcoholic solution from which caustic potash ceased to throw down any precipitate was decanted, and a portion of the alcohol separated by distillation. It was then largely diluted with water, by which it was only slightly troubled; the resin was precipitated by muriatic acid, collected on the filter, and washed by repeated affusions of hot water. After drying at 212° Fahr. this resin was *wholly dissolved by common alcohol in the cold.* According to Unverdorben the resin of sandarach consists of three resins, one thrown down from the alcoholic solution of the crude resin by caustic potash, the resin C. of Unverdorben and of the present paper, and two which remain in solution unaffected by the potash*. When these mixed resins are separated from the potash by muriatic acid, in a way similar to that above described, he states that boiling alcohol dissolves the one and leaves the other. In my experiments, as above detailed, cold alcohol and cold ether also dissolved the whole of what I supposed to contain two resins; while from the solution of the crude resin, by simple dilution a precipitate fell, not noticed by Unverdorben, and possessing characters different from those exhibited by any of the three resins described by that experimenter.

Evaporated and heated at 212° Fahr., as long as any apparent change was produced, the alcoholic solution gave a bright yellow resin, brittle when cold, but softening at the temperature of boiling water.

* Thomson's Organic Chemistry, p. 529.

A. 10·407 grains of it in this state gave $\ddot{C} = 28·83$, and $\dot{H} = 9·40$.

As this does not give a formula containing C_{40}, I exposed the resin dried in mass at 212° Fahr. to a higher temperature, when it melted, and frothed up, giving off vapours. To obtain it free from water and any other volatile substances it might retain, I evaporated a second portion of the alcoholic solution, and kept the resin in the state of a thin film for forty-eight hours at 200° Fahr.

B. 10·515 grains now gave $\ddot{C} = 28·58$, and $\dot{H} = 9·295$.

Still further heated for twenty hours at 250° Fahr., the resin was yellow and brittle, and

C. 11·69 grains gave $\ddot{C} = 32·055$, and $\dot{H} = 10·22$.

These three results are equal respectively to

Dried in mass at 212°.	In a thin film.	
	At 200° for 48 hours.	Further 20 hours at 250° Fahr.
Carbon = 76·601	75·08	75·82
Hydrogen = 10·038	9·82	9·71
Oxygen = 13·361	15·10	14·47
100	100	100

The analyses B. and C. agree very closely with the formula $C_{40} H_{31} O_6$, which gives

Carbon	= 75·59
Hydrogen	= 9·56
Oxygen	= 14·85
	100

The slight excess of carbon in the third analysis, if not an error of experiment, indicates that the heating had been carried a little too far; while the similar excess both of carbon and hydrogen in the resin dried only at 212°, would imply the presence of a volatile carbo-hydrogen, which is wholly expelled only after long-continued heating. A familiar example of the presence of such a volatile compound, we have in the association of oil of turpentine with common resin; and the fact that most of the resins yield on distillation with water a volatile oil, gives ground for believing that the presence of substances analogous to oil of turpentine may tend more or less to modify or vitiate the results obtained by the analyses of resinous bodies, when sufficient precautions are not taken to ensure their expulsion.

III. *Resins precipitated by Caustic Potash.*—The precipitate thrown down by caustic potash from the alcoholic solution of the sandarach of commerce, dissolved readily in a hot dilute solution of caustic potash. From this solution largely diluted with water, the resin was precipitated by dilute muriatic acid, and afterwards washed on a filter till it ceased to render the water acid. Being then boiled in water, dried at 212°, and digested with boiling alcohol, only a small quantity was taken up. The

solution on evaporation gave a pale-yellow resin which did not fuse at 250° Fahr., but cohered at 300° Fahr.

A. 10·817 grs. gave $\ddot{C}$ = 29·875, and $\dot{H}$ = 9·59.

As this *first* solution was likely to contain a portion of the more soluble resin B. carried down by the insoluble potash salt, when precipitated from the solution of the crude resin, the undissolved portion was boiled in a second and third quantity of alcohol. This third solution was evaporated, and the pale-yellow resin heated to 230° Fahr. for forty-eight hours.

B. 8·3 grs. gave $\ddot{C}$ = 23·1, and $\dot{H}$ = 7·45

These two analyses are equal to

	A.	B.
Carbon	= 76·37	76·95
Hydrogen	= 9·85	9·97
Oxygen	= 13·78	13·08
	100	100

The result of the first analysis is intermediate between those obtained from resins A. and B., the second which certainly represents the constitution of a purer form of the resin, approaches very nearly to the constitution of resin A. represented by the formula $C_{40}\ H_{31}\ O_5$.

It would appear, therefore, that one resin A. is to a certain extent soluble in an alcoholic solution of B., but that in some of the varieties of sandarach the quantity of A. actually present is greater than can be thus taken up, in consequence of which a portion sometimes remains behind undissolved when the natural resin is digested in cold alcohol. On treating with caustic potash, however, resin A. is wholly, or more correctly, perhaps almost entirely thrown down along with another resin C. and a small adhering portion of B. On decomposing this potash salt, as above described, with muriatic acid, the mixed resins are obtained and may be separated by boiling alcohol. Resin A. and the small quantity of B. are dissolved, giving a brownish yellow solution, from which on cooling, A. is in a great measure precipitated. Resin C. remains behind of a brown colour. After boiling in distilled water it is obtained in the form of a grey friable mass, which becomes yellowish when heated for twenty-four hours at 250° Fahr., but does not melt. At 500° Fahr. it melts into a brown semifluid mass, and speedily decomposes.

IV. *Resin* C. *of Sandarach.*—The mixed resins obtained from the potash salt by muriatic acid were boiled in repeated portions of common alcohol as above described. The insoluble portion was, in the hot alcohol, soft, glutinous, and of a brown colour. It was boiled in water, by which it was freed from alcohol, becoming hard and friable. Dried at 250°, it was in the state of a yellow powder.

A. 7·044 grs. burned in the air left 0·114 grs. of a grey residue, chiefly carbonate of lime, or 1·61 per cent.

B. 8·97 grs. gave $\ddot{C}$ = 24·405, and $\dot{H}$ = 7·614 grs.
C. 9·08 grs. gave $\ddot{C}$ = 24·46, and $\dot{H}$ = 7·52 grs.

corrected by A. these two analyses give

	B.	C.	($C_{40} H_{30} O_6$) gives
Carbon	75·59	75·53	75·83
Hydrogen	9·47	9·35	9·28
Oxygen	14·94	15·12	14·89
	100	100	100

It is remarkable, if the experiments above detailed are to be depended upon, that the only difference in constitution between resins B. and C. consists in the presence in the former of thirty-one, and in the latter of only thirty equivalents of hydrogen, while their respective solubilities in alcohol, their fusibilities and general relations to heat are so very dissimilar. We know as yet too little of their several relations to other substances to enable us to speculate on the mode in which the elements are grouped in the two compounds.

Conclusions.—The sandarach of commerce consists of three resins, all of which possess acid properties.

1. A = $C_{40} H_{31} O_5$ a white or yellow powder, sparingly soluble in alcohol, more so in boiling than in cold, melting with difficulty, and decomposing at a temperature little above that at which it melts, existing in sandarach only in a small proportion, and partly separated on treating the natural resin with a large quantity of alcohol, and partly thrown down from this solution of the natural resin by caustic potash along with the insoluble resin C.

2. Resin B = $C_{40} H_{31} O_6$ bright-yellow, brittle, softening at 212° Fahr., having the resinous odour of sandarach, dissolving largely in cold alcohol, constituting at least three-fourths of the natural resin, and remaining in solution when A. and C. are precipitated by caustic potash.

3. Resin C = $C_{40} H_{30} O_6$ a pale-yellow powder, nearly soluble in boiling alcohol, requiring a high temperature to melt it, and at the same time undergoing decomposition. It exists in sandarach in much larger quantity than resin A., and is obtained in a pure state by decomposing with muriatic acid the precipitate thrown down by caustic potash, and boiling first in water and afterwards in repeated portions of common alcohol.

I shall have occasion hereafter to describe several other nearly insoluble resins, differing in composition from those above described, but I may here introduce the remark, that we are already prepared to anticipate unlike *rational* formulæ for the soluble and insoluble resins; since the number of atoms of oxygen contained in our *empirical* formulæ appear to have no relation to these properties of solubility and

fusibility. This is strikingly shown in the case of the resins above described, and there are many others in which this fact is equally apparent.

Note.—The disagreement between some of the details of the above examination of the resin of SANDARACH, and those of UNVERDORBEN, to whom we are indebted for the only previous methodical examination of a large number of the resins, is to be ascribed chiefly I believe to the mode in which UNVERDORBEN examined the resins. Being unable to have recourse to the ultimate analysis of the substances he obtained, he distinguished them chiefly by their physical characters, which in many cases are very fallacious. It is possible, however, that different specimens of the resin may contain the several resins in different proportions.

VII. *Resin of the Pinus Abies or Spruce Fir, sometimes called Thus, or Common Frankincense.*

This resin is brittle but soft, and easily scratched by the nail; of a pale-yellow colour, and semitransparent. It occurs in rounded masses of various sizes, mixed with chips of wood. When melted in hot water and strained through a cloth, it forms the Burgundy pitch of commerce. In cold alcohol it dissolves readily, leaving a variable proportion of a second resin B. in pure white opaque masses. This second resin is not insoluble in the cold, but only more sparingly soluble than resin A, and readily dissolves in hot alcohol. It should therefore be washed with several affusions of cold alcohol, and dried by strong pressure between folds of bibulous paper. Thus obtained and dried it is in the form of a white farinaceous powder, which requires a temperature of 300° + FAHR. to bring it into complete fusion; and on cooling from fusion it is pale-yellow, transparent, and brittle, differing little in appearance from resin A. after it has been similarly fused.

I. *Resin* A.—The solution of the soluble resin was evaporated, and exposed in a thin film for thirty-six hours to a heat not exceeding 200° FAHR.; it was still soft at that temperature, and on cooling became brittle, but did not contract and crack. In this state,

A. 12·288 grains gave $\ddot{C} = 33{\cdot}67$, and $\dot{H} = 10{\cdot}35$ grains.

A portion of the resin thus analysed was again heated in a thin film for eighteen hours at a similar temperature. It was still beautifully transparent and pale-yellow, and on cooling contracted and cracked in various directions. In this state,

B. 11·63 grains gave $\ddot{C} = 31{\cdot}98$, and $\dot{H} = 9{\cdot}731$.

Another portion of the alcoholic solution was evaporated and heated as before for a still longer continuance, and to a temperature a little higher. It began now to assume a reddish tinge on the surface, and, on cooling, the fissures which traversed the yellow mass were of a beautiful red colour. Again analysed,

C. 12·35 grains gave $\ddot{C} = 34{\cdot}083$, and $\dot{H} = 10{\cdot}238$.

These three analyses are equal respectively to

	A.	B.	C.
Carbon	= 75·76	76·01	76·31
Hydrogen	= 9·35	9·29	9·21
Oxygen	= 14·89	14·70	14·48
	100	100	100

I consider the state of the portion employed for the second analysis B. to represent most nearly the normal condition of the resin, and the result of this analysis agrees almost exactly with the formula $C_{40}\ H_{29}\ O_6$. Thus

40 Carbon	= 3057·480	= 76·01
29 Hydrogen	= 364·919	= 9·07
6 Oxygen	= 600·000	= 14·92
	4022·399	100

The results of the whole three analyses are very near these calculated numbers, and yet they illustrate very distinctly what I have frequently had occasion to remark in the study of the resins, that we can rarely depend on the results of any one analysis, however carefully performed. To obtain the resin in a normal state, free on the one hand from adhering water, alcohol, or ether, and on the other from any carbo-hydrogen or other compounds which may be present in it in its natural state, it must be heated for a length of time, and yet neither so long nor to so high a temperature as to induce incipient decomposition. Much attention therefore is required to the process of heating; and when this attention is paid, some change of appearance will always be observed which may be presumed to indicate decomposition; still where doubt remains, or where a formula cannot be obtained, a series of analyses of the resin, in its several stages of heating or drying, can alone determine what numbers are to be considered as expressing most nearly its true elementary constitution.

II. *Resin* B. *of the Pinus Abies.*—I have already stated that cold alcohol leaves undissolved a white opake portion, in greater or less quantity, when the natural resin is digested in this liquid. By repeated solutions in hot alcohol, partial evaporation, and pressure between folds of bibulous paper, this resin may be obtained nearly free from the more soluble resin A. The three portions subjected to analysis were prepared from as many separate quantities of the natural resin, and the constancy of the results may be considered as indicating the degree of confidence to be placed in the formula deduced from them.

A. 12·247 grains heated till it was completely melted and began to assume a reddish hue, gave $\ddot{C} = 34·35$, and $\dot{H} = 10·37$ grains.

B. 11·94 grains heated only till it cohered, and was brittle when cold, gave $\ddot{C} = 33·767$, and $\dot{H} = 10·42$ grains.

C. 8·495 grains after perfect fusion gave $\ddot{C} = 24·02$, and $\dot{H} = 7·18$ grains.

These results are equal to

	A.	B.	C.
Carbon	= 77·55	78·20	78·182
Hydrogen	= 9·40	9·69	9·390
Oxygen	= 13·05	12·11	12·528
	100	100	100

And they indicate the formulæ $C_{40}\ H_{29}\ O_5$, which gives

$$\left.\begin{array}{ll}\text{Carbon} & = 77{\cdot}95\\ \text{Hydrogen} & = 9{\cdot}30\\ \text{Oxygen} & = 12{\cdot}75\end{array}\right\}100.$$

Conclusions.—The resin of the *Pinus Abies*, therefore, consists of two acid resins, represented respectively by

A = $C_{40}\ H_{29}\ O_6$, easily soluble in cold alcohol, fusible about 212° Fahr.

B = $C_{40}\ H_{29}\ O_5$, sparingly soluble in cold alcohol, fusible at 300° Fahr.

The presence of a second and crystallizable resin in this natural product has been already observed by Baup*; and it is probable that many other of the resins which exude from trees belonging to the pine and its kindred tribes, contain, in like manner, a crystallizable resin possessed of a peculiar elementary constitution. These two classes of resins have hitherto been distinguished only by the general names of *pinic* and *sylvic* acids, though the several members of each class are at least as different in composition as the two resins themselves, which have been regarded as the types of each class.

This observation, suggested by the examination of the natural resin of the *Pinus Abies*, is confirmed by an analysis of Hess†, of a crystalline resin which he obtained as sylvic acid, but which he found to be composed of $C_{40}\ H_{30}\ O_8$, and for which, though he is unacquainted with the natural resin from which it was extracted, he has proposed the name of *Oxysilvic*. This name it is obvious would apply to the crystalline resin of the *Pinus abies*; it is therefore desirable that some other more general nomenclature for this class of bodies should be devised.

The quantity of the crystallizable resin which they contain varies in different portions of the natural product. Such is the case with elemi resin, of which some specimens dissolve completely in cold alcohol; such is the case with colophony; and such also is the case with the resin above analysed. In examining a mass of the natural resin, parts of it will be found to be harder than the rest, whiter, having a lamellar fracture, being tough and yet friable; in these portions the crystallizable con-

* Annales de Chimie et de Physique, tom. xxxi. p. 108. He calls it *abietic acid*, and describes it as an acid resin soluble in 7·5 of common alcohol (88 per cent.) at 57° Fahr., and crystallizing in quadrangular plates.

† Poggendorf's Annalen, tom. xlvi. p. 326.

stituent exists in greatest quantity. If the action of the air have any influence in changing the chemical constitution of the natural turpentines as they exude from the trees, it is not difficult to understand either how one portion should combine with five and another with six of oxygen, or how the quantity of each of these compounds present in any two masses should be found to be very different.

The solutions of both the resins of *Pinus abies* in alcohol gave precipitates with an alcoholic solution of acetate of lead, but I have not examined any of their salts.

VIII. *Resin of Olibanum, the Frankincense of the Ancients.*

When the olibanum of the shops, consisting of rounded masses, differing to the unpractised eye only in depth of colour, was introduced into alcohol, some pieces were rendered clear and transparent, while others became almost immediately white and opake, from a white powdery coating left on their surface as the soluble portion is taken up by the fluid. That the mixture of these two varieties had not been made recently, appeared from the manner in which pieces of the different kinds cohered and were occasionally imbedded in each other, as if the contact had taken place while they were comparatively soft.

I. Before I perceived this difference a considerable portion was already dissolved. I therefore filtered the solution, and evaporated a portion of it in a thin film. The two varieties also were separated from each other, and covered each with fresh alcohol.

Of the resin obtained by evaporating the solution of the mixed varieties,

11·236 grains gave $\ddot{C} = 30·72$, $\dot{H} = 10·40$, or per cent.,

Carbon	= 75·59	= 40 atoms.
Hydrogen	= 10·28	= 32·2 atoms.
Oxygen	= 14·13	= 5·71 atoms.
	100	

II. The lumps which had retained their transparency when first digested in cold alcohol, were acted on more slowly by this menstruum than the other variety. They however after a time became covered with an opake white coating, but it was less in quantity than the similar insoluble matter left by the other. The pale-yellow solution was evaporated in a thin film, and kept for sixty hours at a temperature of 200° Fahr. The resin was pale-yellow, brittle, and cracked on cooling, and became soft at 220° Fahr.

A. 13·1 grains gave $\ddot{C} = 37·58$, and $\dot{H} = 12·69$.

B. Another portion of the same solution evaporated and heated for eighteen hours, gave a resin of which 10·17 grains gave $\ddot{C} = 29·047$, and $\dot{H} = 9·767$.

9·695 grains gave $\ddot{C} = 27·73$, and $\dot{H} = 9·376$.

These are equal to

		A. (2.)	B. (3.)	C. (4.)
Carbon	=	79·33	78·98	79·09
Hydrogen	=	10·76	10·67	10·73
Oxygen	=	9·91	10·35	10·18
		100	100	100

These results agree very nearly with the formula $C_{40}\ H_{32}\ O_4$, being that originally adopted by Rose to represent the constitution of colophony. This formula gives

40 Carbon	=	3057·480	=	79·27
32 Hydrogen	=	399·347	=	10·36
4 Oxygen	=	400·000	=	10·37
		3856·827		100

The most marked disagreement is in the amount of hydrogen which by analysis is about one tenth per cent. greater than it should be, allowing for the usual errors of analysis. The formula $C_{40}\ H_{33}\ O_4$ would give 10·6 per cent. of hydrogen, which is probably too near the quantity found to represent the amount actually present in the resin.

At the same time I would take the present opportunity of repeating*, that in none of the formulæ deduced from the analyses detailed in the present investigation, is the number of equivalents of hydrogen to be considered as *absolutely* determined. Whatever precautions may be taken to obtain any given resin in a *normal* or perfectly pure state, and to avoid the ordinary errors of experiment, the examination of every new member of this interesting family convinces me that though the formula deduced from analysis may express very truly the relations between the number of the equivalents of carbon and oxygen, yet that the hydrogen is doubtful to the extent of one or two equivalents always in excess, and that to this extent, therefore, the formula I have given may be still open to correction.

III.—1. Of that which became soonest opake from containing the largest quantity of gum, two several portions of the solution were evaporated in thin films, and heated for sixteen hours at 250° Fahr.

A. Of the first portion 10·22 grs. gave $\ddot{C}$ = 28·67, and $\dot{H}$ = 9·575 grs.

B. Of the second portion 6·33 grs. gave $\ddot{C}$ = 17·693, and $\dot{H}$ = 5·908 grs.

These are equal to

		A. (5.)		B. (6.)
Carbon	=	77·57	=	77·29
Hydrogen	=	10·41	=	10·37
Oxygen	=	12·02	=	12·34
		100		100

* Ante, p. 286.

The formula $C_{40}\ H_{32}\ O_5$ gives

Carbon	=	77·28
Hydrogen	=	10·09
Oxygen	=	12·63
		100

2. Exhausted with more alcohol, this portion gave a resin of a different constitution, which did not harden so readily on cooling even after long heating, and was obtained brittle only in very thin films.

C. 10·435 grs. gave $\ddot{C}$ = 28·39, and $\dot{H}$ = 9·35.
D. 5·67 grs. gave $\ddot{C}$ = 14·49, and $\dot{H}$ = 4·867 or

		C. (7.)		D. (8.)
Carbon	=	75·23	=	74·66
Hydrogen	=	9·95	=	10·07
Oxygen	=	14·82	=	15·27
		100		100

The formula $C_{40}\ H_{32}\ O_6$ requires

Carbon	=	75·36
Hydrogen	=	9·84
Oxygen	=	14·80
		100

These discordant results seemed to imply that this gum resin contains two resins, of which the one is represented by $C_{40}\ H_{32}\ O_4$, and the other by $C_{40}\ H_{32}\ O_6$. This would account for the formula $C_{40}\ H_{32}\ O_5$ given by the above analyses A. and B., on the supposition that the resin employed in these analyses was a mixture of the two, as well as for the occurrence of the resin with four equivalents, *alone*, in some varieties of olibanum.

3. With the view of satisfactorily determining this point, a further quantity of olibanum was immersed in alcohol, and the portions which soonest exhibited a coating of gum were selected. Treated with cold alcohol for several days with occasional agitation, these gave a pale yellow solution which was decanted. The undissolved part was boiled with more alcohol, and a much paler solution obtained. This paler solution evaporated in a thin film, as usual, gave a brittle resin, having the colour and much of the smell of colophony, of which

E. 7·20 grs. gave $\ddot{C}$ = 19·51, and $\dot{H}$ = 6·43 or per cent.

Carbon	=	74·93
Hydrogen	=	9·92
Oxygen	=	15·15
		100

which agrees with the results C. and D., and leaves no doubt that a resin with six atoms of oxygen is one of those which exist in olibanum. The first, or yellower solution, gave a softer resin, the analysis of which was lost by a failure in the burning.

4. On examining the olibanum of commerce after the above experience of the presence of different resins, it is easy to distinguish by the eye at least two varieties; one in rounded brittle, brownish-grey, opaque masses of various sizes; the other in long tears as if it had flowed more easily from the tree, and been less rounded by attrition, often softer, less brittle, and less dull in aspect. There occur also other pieces not to be classed with either, the composition of which can be determined only by a separate examination*. The first variety described is that which contains most gum.

A few pieces of this were carefully selected and treated with alcohol for several days in the cold till the resin was entirely exhausted. The *whole* of the solution was evaporated together, and the resin heated at 250° Fahr. for sixteen hours.

8·03 grs. gave $\ddot{C}$ = 21·87, and $\dot{H}$ = 7·215 or

		(10.)	$C_{40}H_{32}O_6$ gives
Carbon	=	75·31	75·36
Hydrogen	=	9·98	9·84
Oxygen	=	14·71	14·80
		100	100

These selected portions, therefore, consisted wholly of gum in large quantity, and of a resin containing six of oxygen; and as we have already seen that those pieces which include less gum, consist wholly of gum and a resin containing only four of oxygen, and having much of the smell and other properties of colophony, I have thought it unnecessary to search for any other explanation of the discordant results exhibited in analyses 5 and 6, than the supposition that the resin employed in these analyses was a mixture of the two. Had I chosen to omit these two analyses from the present paper, no discordance would have appeared among the results detailed. I think it better, however, that in an investigation like the present, no important steps should be omitted, both because they illustrate the precautions it is necessary to adopt in order to obtain a pure substance, and because others who may repeat my experiments, should they obtain repeated results agreeing so closely, and indicating so distinct a formula as the analyses 5 and 6 (above), might consider themselves justified, without further examination, in pronouncing me to have been in error.

Conclusions.—The gum resin olibanum of commerce consists of a mixture of at least two gum resins, the resinous ingredient in each of which differs from that of the other in composition and properties.

1. The rounded, opaque, dull, hard, and brittle pieces, which speedily become covered

* These remarks I believe to apply generally to the olibanum as it is met with in this country, the first quantity I examined being bought in Edinburgh six years ago, the second in London within these few months.

with a white crust when immersed in alcohol, contain an acid resin (A.) = $C_{40} H_{32} O_6$. This variety constitutes the larger portion of the olibanum of commerce, and is the more fragrant when burned. Its composition is determined by the four concordant results (7, 8, 9, 10). It contains a variable quantity of a volatile oil, as is the case with nearly all the resins, by which some specimens even after long heating are prevented from immediately becoming brittle when allowed to cool.

2. The clearer, yellower, less brittle and opaque pieces, generally in long tears (stalactitic?) as they have flowed from the tree, and which give less gum when treated with alcohol, contain a resin represented by $C_{40} H_{32} O_4$, and having considerable resemblance in smell and in its other properties to colophony.

Whether these two varieties issue from different parts of the same tree, or at different seasons, or whether the true olibanum is mixed with the produce of another tree, it is not easy to determine. We can scarcely believe that the two varieties issue from the same tree under the same circumstances.

As I have already said, there may be other resins mixed with these in smaller quantity, in the olibanum of commerce, in regard to the composition of which I have made no examination.

General Observations.

We have already seen in the first and second parts of this inquiry, that the resins may differ very widely in the number of equivalents, not only of oxygen, but also of hydrogen, which they contain; and founding on this difference in respect of the hydrogen, we have seen reason also to divide such as have hitherto been analysed into two groups, represented respectively by the general formulæ

$$C_{40} H_{32-x} O_y \text{ and}$$
$$C_{40} H_{24-x} O_y.$$

The resins described in the present paper belong to the first of these groups, and illustrate very clearly the differences which may exist in the number of equivalents of hydrogen among the several members of the same group. A comparative inspection of the formulæ is sufficient to satisfy us that such differences exist in nature.

Resin of *Pinus abies* B = $C_{40} H_{29} O_5$
Resin of Sandarach A = $C_{40} H_{31} O_5$

Resin of *Pinus abies* A = $C_{40} H_{29} O_6$
Resin of Sandarach C = $C_{40} H_{30} O_6$
Resin of Sandarach B = $C_{40} H_{31} O_6$
Resin of Olibanum A = $C_{40} H_{32} O_6$.

At present I do not dwell on these partial generalizations, as the results of other experiments which I shall hereafter have occasion to detail will render necessary a slight modification of one or both of the above general formulæ.

Durham, May, 1839.

XIX. *Researches in Embryology.—Second Series.* By Martin Barry, *M.D. F.R.S.E., Fellow of the Royal College of Physicians in Edinburgh. Communicated by* P. M. Roget, *M.D. Sec. R.S.*

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In a former communication† I described the mammiferous ovum in its several periods of formation. The present paper is intended to trace it through the early stages of development.

What is known, or supposed to be known, of the evolution of the mammiferous ovum in its early stages, mainly rests on observations made, not in Mammals, but in Birds. Direct observations have been so few and so isolated, that between the time when the coitus takes place, and that of the incipient appearance of the vertebræ, there exists a dark period of which very little is really known. This hiatus it is one of the objects of the present paper to assist in filling up.

The ova of the Vertebrata generally were the subjects of investigation in my last memoir, it being then intended to demonstrate the essential identity in form, of certain structures which exist in the four classes of vertebrated animals. The ovum as then considered was in a state of comparative, though not entire, repose. The present series of researches, on the contrary, investigates the ovum while undergoing rapid changes. In order the more completely to watch the progress of these changes, it seemed desirable to confine the attention to a single species. The one I selected was the Rabbit, to which animal all general remarks made in this paper will refer‡.

For the illustration of a subject like the present, which may be compared to a series of metamorphoses, it will be obvious that we ought to be in possession of a *suite* of stages. These I trust have been obtained, though not without difficulties at times in the highest degree discouraging and inseparable from the very nature of the subject,—difficulties felt by De Graaf, Cruikshank, Haighton, Prevost and Dumas, Baer, and others. But there existed other difficulties, the best evidence of which is the result, that I am compelled, however reluctantly, to call in question some views which were considered to be settled; and these embracing points of cardinal importance. For example, according to my observations the embryo does not arise in the substance of a membrane.

The discrepancies to be found in the accounts of authors on the ovum of Mam-

† Researches in Embryology, First Series. Philosophical Transactions, 1838, Part II. p. 301.

‡ Among the figures will be found several from the Tiger, for an ovary of which animal I am indebted to the kindness of Professor Owen.

malia, and the confused nomenclature of its membranes, appear referable to the absence of early observations in continuous succession. Observers have not directed their attention to the ovum *post coitum* before it leaves the ovary; and they cannot be said to have thoroughly examined it in the Fallopian tube. Now so rapid are the changes which the ovum undergoes at the period in question, that had I not very often seen it in both of those localities, it would have been impossible for me at least to understand it in the uterus. And in proof that others failed to do so, it may be stated that ova of the Dog measuring half a line, have been described by eminent observers as consisting of a single membrane; whereas in the Rabbit, according to my observations, ova of still minuter size may consist of four membranes in addition to the embryo, (one of these membranes being composed of two laminæ); to which it may be added, that I find one membrane to disappear by liquefaction within the ovum while the latter is in the Fallopian tube.

From what has been stated, it will be obvious that in undertaking researches in so difficult a subject as that of embryology, the mind should not be pre-occupied with any theory. I certainly had none to establish. If I was at all prepossessed, it was in favour of existing doctrines; and it has been in spite of such prepossession that fact after fact has gradually but irresistibly compelled me to form other views. In the following pages there will be found no speculations, as I have confined myself to a simple delineation of appearances, and to the most obvious conclusions arising from them. If in any points I have been mistaken, that indulgence will, I trust, be accorded which may be fairly claimed in exploring one of the most hidden regions of physiology. That in the main facts I have not erred seems probable, from the repeated opportunities afforded for their confirmation. The number of Rabbits examined considerably exceeds a hundred, and I have recorded in my notes the particular results regarding eighty-nine. Besides ova that were still present in the ovary and apparently destined to escape, ninety-three have been found in the Fallopian tube, and two hundred and thirty-six in the uterus. I have kept a separate record of the measurements and other particulars of most of these. Tables will be given (par. 319.), showing the diameter, general condition, and locality, of two hundred and fifty-six of the minuter of these ova, very few of which exceeded in diameter half a Paris line, and by far the greater number were considerably below this size, some indeed not exceeding $\frac{1}{75}$th and even $\frac{1}{35}$th of a Paris line. Of these ova I have preserved sixty-six. The foregoing will serve to show that my conclusions have not been drawn from solitary facts or isolated observations†.

† The following testimony to the importance of the history of development, is from the pen of an eminent observer, (E. Huschke, in Meckel's Archiv, vol. vi. p. 1.) "Systematic physiology rests especially on it, and can never rapidly advance unless it becomes more perfect, for this it is which gives to the philosopher the material wherewith to rear a solid fabric of organic life. Hence in anatomy and physiology, our endeavours ought more than is now the case to have reference to it; in other words, we should constantly examine not only every organ, but every material, and also every action, with the inquiry, *how did they originate?*"

(The measurements throughout this paper, as in the former one, are stated in fractions of a Paris line, and thus expressed (‴). As a simple mode of reducing this fraction into (what is very nearly) the equivalent fraction of an English inch, I recommend multiplying the denominator of the former by $11\frac{1}{4}$. See the "Table of Measurements" (par. 320.). The actual sizes of some of the ova are represented at the foot of Plates VI. and VII.

The Mature and the Immature Ovum.

120. The difference perceptible between ova in these two states appears to me to consist in the condition of the yelk. In the immature ovum the yelk contains separate oil-like† globules, diffused in a fluid (Plate V. fig. 85. *d*); while in the ovum that is mature, the yelk presents a peripheral stratum, sometimes appearing granulous, and at others seeming to consist of vesicles pressed together into a polyhedral form, its centre being in the state of fluid.

121. The globules of the yelk just mentioned as oil-like in their appearance in the immature ovum (fig. 85. *d*), are in reality vesicles. In fig. 87. are some of those vesicles from an immature ovum of the Tiger, in which animal I found them exceedingly distinct. But besides being true vesicles, those globules contain objects which themselves are also vesicles; the latter in some instances presenting opacities in their interior, and they are often observed to be pressed into an irregular shape‡.

122. The globules contained in the vesicles ("cells") represented by Dr. SCHWANN§ from the yelk-cavity of a Hen's egg do not exhibit the appearance of vesicles so decidedly as the above. In the Cat, however, I have found the vesicles of the yelk to contain a globule very much resembling that just referred to as figured by SCHWANN, yet the outer vesicles had the same high refracting power as those from the Tiger (Pl. V. fig. 87.), and in this respect, therefore, differed from those in the figure by SCHWANN. Is the difference referable to a difference in age‖?

Effects produced on the Ovum in the Ovary by Maceration.

123. On a former occasion (*l. c.* par. 50.) I referred to the effects of maceration, as increasing the probability that a proper membrane of the yelk existed generally in the class Mammalia; for it was shown that although the thick transparent membrane of the ovum or "zona pellucida" (*f*) by imbibition had become distended, the yelk-

† The term "*oil-like*" is used, as in my former memoir, to describe simply the appearance and not the nature of the globules to which it is applied.

‡ It is an interesting fact, as several figures in my "First Series" (*l. c.* Plate V. figs. 14, 15, 16,*) serve to show, that the yelk-globules (vesicles) collect, and perhaps originate, around *the germinal vesicle*.

§ Mikroskopische Untersuchungen über die Uebereinstimmungen in der Struktur und dem Wachsthum der Thiere und Pflanzen. Tab. II. fig. 2. Berlin, 1838–9.

‖ Perhaps, however, it is the globules of the "*discus vitellinus*" rather than those of the yelk-cavity in the egg of the Bird, with which the globules of the substance usually called the yelk in the mammiferous ovarian ovum are to be compared (par. 174. first Note. par. 318.).

ball still retained its size and form. In the present paper, Plate V. fig. 88. affords a proof of this in an ovum of the Tiger. Here, however, in addition to the yelk continuing spherical, its proper membrane (*e*) was very distinctly visible.

124. The most conspicuous change produced by maceration is distention of the membrane *f*, but I have observed the germinal vesicle also before disappearing to become elliptical. See the figure just referred to and also fig. 89., which exhibits the germinal vesicle (*c*) of the same ovum on a larger scale. From the germinal spot (*b*) in this instance there were seen to have arisen three membranes or vesicles, its central part consisting of a fourth, which appeared to contain a pellucid fluid. Between these membranes or vesicles of the former spot, were granules and a fluid (par. 298.) the granules being situated for the most part near the centre.

The Rut.

125. It is known that at this period there occurs increased vascularity of the parts in general, and of certain Graafian vesicles in particular. I have found that the number of Graafian vesicles appearing to become prepared, by enlargement and vascularity, for discharging their ova, exceeds the number of those that actually discharge them (par. 126.). The fluid of the Graafian vesicles in general which are situated at the surface of the ovary, is more viscid now than at other seasons. The degree of this viscidity, however, as well as the condition of the yelk, seems to depend on the degree of advancement of the period in question. In ova taken from enlarged and vascular Graafian vesicles, the germinal vesicle is at the periphery, and the yelk mature (par. 120.). I have also in some instances observed the peripheral stratum of the yelk to have become more finely granulous than in usual states of the mature ovum *ante coitum*. The changes in the tunica granulosa and retinacula, incipient perhaps at this period, will be more particularly mentioned among those referable to the coitus.

The Ovum in the Ovary post coitum†.—*First and Second Stages of Development.*

126. I have found it extremely difficult to distinguish with precision between the changes referable to the rut, and the further changes resulting from the coitus. For reasons given in the introduction to this memoir, it did not seem sufficient to see the state of ova first in the Fallopian tube. But then it was equally unsatisfactory to examine ova still in the ovary; for at first I was not in possession of any means of distinguishing those that were really destined to be discharged, as in addition to the Graafian vesicles, from which ova would have been expelled, I have (as already stated)

† As researches of this kind would be impossible, or the results of no value, without the means of determining precisely the period between the coitus and the death of the animal, I shall be excused if I mention for the professional reader, 1. That persons were employed who might be relied upon, and were fully competent to judge of the condition of the female rabbit in reference to the rut: 2. That the coitus was in every instance *seen*, and the time as well as the degree of readiness for the reception of the male particularly noticed and recorded: and 3. That immediately after the coitus the female Rabbit was removed and kept separate from the male.

generally found several others that had become enlarged and vascular (par. 125.). It therefore was an object of great interest to meet with ova that were on the point of entering the tube.

127. The periods of 4, 6, 8, and 8½ hours *post coitum*, were found too short, the ova being still within the ovary, and apparently not very near the time of their expulsion. A rabbit was examined at eleven hours, when the ova were found to have made their exit from that organ; and one at ten hours, with the same result. Another was killed at nine hours; the ova were still within the ovary, and their Graafian vesicles presented no decided indication of an approaching rupture. I tried 9¼ hours, when the ova were again found within the ovary; while in another instance at nine hours they had escaped. This was discouraging, but it seemed worth while to persevere. At length, after nearly a score of rabbits had been devoted to anatomical inspection, for the single object of determining the condition in which the ovum leaves the ovary, the parts were found in a state precisely what I had so much desired to meet with; one of these animals at ten hours yielding me two ova that had left the ovary and advanced an inch into the tube, and two others that were still in the ovary, but beyond all doubt on the point of following them.

128. According to my observations, then, ova of the Rabbit destined to be developed are frequently discharged from the ovary in the course of nine or ten hours *post coitum*. BURDACH† refers to only one authority on this subject, stating that CRUIKSHANK saw the Graafian vesicles of the Rabbit to burst in the short period of two hours. From CRUIKSHANK's paper‡, however, it appears that this was observed in a single instance only. KUHLEMANN§ found Graafian vesicles of the Sheep to have burst at the end of the first day; and HAUSMANN‖ observed that in the Hog they had nearly all burst in seventeen hours. The conclusions of PREVOST and DUMAS¶ as to the time of bursting of the Graafian vesicles in Dogs, appear to rest chiefly on the period when those observers found ova in the uterus, from which nothing can be determined as to when they left the ovary. I have recorded in my notes several instances in which, after a much longer period than nine or ten hours, the ova (in the Rabbit) had not escaped. But in those instances there was no proof that any ova were destined to escape,—in other words, that the coitus had been productive. Still, however, the condition of the animal, and more particularly the degree of its advancement in the rut, probably occasion considerable differences in this respect. Yet I am satisfied that ova very frequently leave the ovary in nine or ten hours; to have determined which, it will be hereafter seen (par. 166.) is a point of some importance.

129. Several observers appear to have supposed the ova to be still present in the ovary after their escape. CRUIKSHANK††, for instance, mentions a little body which he found on the top of the *corpus luteum* three days *post coitum*. That little body he

† Die Physiologie als Erfahrungs Wissenschaft, vol. ii. p. 12.

‡ Philosophical Transactions, 1797.

§ BURDACH, *l. c.* vol. ii. p. 12.

‖ Ibid. vol. i. p. 555.

¶ FRORIEP's Notizen, No. 189, p. 198.

†† *L. c.* p. 206.

supposed to be the ovum. What it really was I shall endeavour hereafter to render probable (par. 155.); but it is very unlikely to have been an ovum.

130. It appears from the observations just made known (par. 127.), that in the Rabbit all the ova of one impregnation are discharged at about the same time. This is opposed to the opinion of PREVOST and DUMAS†, that in the Rabbit at least two days elapse before all the ova destined to be developed have left the ovary. That I am correct in this particular, is rendered still more probable by the fact, that in the Fallopian tube, and in the beginning of the uterus, minute ova are generally (though not in every instance) met with lying very near together‡. Having found more than three hundred ova in the uterus and tube, I may perhaps venture to speak with some confidence as to their particular localities, which it has uniformly been my practice to record. A general idea of the situation in which many of the minuter ova have been observed, may be obtained from the Tables (par. 319.).

131. If my endeavours to obtain ova when just on the point of entering the tube were for a long while fruitless, unexpected facts were noticed, amply repaying all the labour. It was in the course of those wearisome endeavours, that the germinal vesicle first presented itself in situations which made me doubt its disappearing at the period hitherto supposed. I saw it in mature ova half-way between the surface and the centre of the yelk,—a locality which was remarkable from the fact, that *ante coitum*, and even while the ovum is yet immature, the germinal vesicle is seen to have passed to the surface of the yelk. Now such a situation of the germinal vesicle would probably have escaped my attention, if the observation had not been many times repeated. Yet on a knowledge of the fact that the germinal vesicle returns to the centre of the yelk, depends the possibility of fully understanding the ovum in some of its future phases.

132. I shall now describe the changes apparently resulting from sexual connexion, observed in the ovum of the Rabbit while still within the ovary. Some minute details will be unavoidable, but so far as is consistent with perspicuity I shall endeavour to be brief.

133. After some hours the germinal vesicle is found to have left its situation at the surface of the yelk and to be *returning to its centre*, from whence it came. About the same time I have observed to have arisen from the surface of the germinal spot a membrane—that is, a vesicle—which speedily enlarged so as to apply itself to the inner surface of the germinal vesicle. The vesicle thus proceeding from the spot, of course imbibed the fluid of the germinal vesicle, which in its new situation appeared finely granulous, and yellowish-brown in colour. The germinal vesicle having now two membranes, was less transparent, and less easily ruptured than before; and I have

† *L. c.* No. 189, p. 199.

‡ It is an interesting fact, that if a larger number of ova than usual escape from one ovary, a proportionally smaller number is discharged from the other.

observed what appeared to be the further effect of this additional membrane, in the vesicle remaining visible, casting a shadow, and even not at all collapsing after being ruptured (Plate V. fig. 92.).

134. The germinal spot, previously on the internal surface of the germinal vesicle, is soon observed to occupy its centre; presenting thus the same change in relation to the germinal vesicle, as the latter undergoes in reference to the yelk-ball. The spot becomes very much enlarged, and in its centre there is now a pellucid point.

135. On some occasions, when the germinal vesicle was observed to be returning from the surface to the centre of the yelk, the yelk viewed with reflected light exhibited the appearance of masses, between which there was a pellucid fluid. At other times I have seen with great distinctness a cavity in the centre of the yelk. Plate V. fig. 93. shows the germinal vesicle (*c*) just entering such a cavity. This figure represents a stratum, apparently of vesicles, forming the periphery of the yelk. Subsequently this stratum has disappeared (the proper membrane of the yelk having in the mean time thickened), and the yelk has become fluid at its surface; while its central portion, in which the germinal vesicle now lies, has become obscure. In a stage still later more of the yelk has liquefied, and in the liquid are granules, the central part of the yelk having now an ellipsoidal form (Plate V. figs. 96. and 97.).

136. The proper membrane of the yelk was shown in my "First Series" (*l. c.* Plate VIII. fig. 70. *e.*) to be present at an early period in the existence of the ovum, but stated to be from its tenuity in Mammalia generally invisible. At the period at present under consideration it suddenly thickens, highly refracting light (Plate V. figs. 94. 96. 97. *e.*), and is often reddish-brown in colour. This thickening of the proper membrane of the yelk is not among the earliest of the changes resulting from sexual connexion, but follows those above described, and for the most part takes place immediately before the discharge of the ovum from the ovary. The stratum of vesicles referred to in the preceding paragraph (fig. 93.) has now disappeared.

137. The thick transparent membrane of the ovum, or "zona pellucida" (*f*), begins to imbibe fluid and distend, so that a minute space, filled with fluid, is visible between it and the yelk-ball (Plate V. figs. 96. and 97. *e.* and *f.*). This change follows the incipient thickening of the proper membrane of the yelk (*e*), and in some instances is not appreciable until after the ovum has made its exit from the ovary.

138. The tunica granulosa (Plate V. figs. 93. 96. 97. g^1.) was shown on a former occasion (*l. c.* par. 64–71. 88.) to be at first a spherical and subsequently a flattened accumulation, on the ovum, of the peculiar granules, or rather vesicles of the ovisac. At the period in question its vesicles hang less tenaciously together, and frequently appear to be passing into a fluid state. The tail-like appendages, as I have called them, of this tunic are now very distinctly seen to be continued into the four persistent retinacula, evidently contributing themselves to perform the same offices (par. 149—151.) as the latter (fig. 96. g^1.).

139. The retinacula (Plate V. figs. 93. 96. g^2.) (described in my "First Series"), at the period now before us, become enlarged, for which there seems to be a provision

ante coitum in the wrinkled state (as formerly mentioned, *l. c.* par. 86. *Note.*) of their investing membrane. In some instances I have observed a number of minute dark globules to be mixed with the vesicles which form these structures. Sometimes, as in fig. 96. g^2., the retinacula, beginning to liquefy, resemble a collection of pellucid drops of fluid.

140. Most of the changes now mentioned I have found to take place before the ovum leaves the ovary. Yet certain of the later ones in some instances are not observable until the ovum has passed into the Fallopian tube. From my observations, therefore, it appears that there is no condition of the ovum uniform in all respects, which can be pointed out as that in which it is expelled; though the same observations lead me to conclude that Plate V. figs. 96. and 97. present a state which is frequent when the discharge takes place, viz. the germinal spot (*b*) has a central pellucid point; it is situated in the centre of the germinal vesicle (*c*); the latter has a dark contour, and perhaps a double membrane; around it is an ellipsoidal mass; the yelk (*d*) is a fluid containing granules; the proper membrane of the yelk (*e*) has thickened, highly refracts light, and is often reddish-brown in colour; there is a minute space, filled with a transparent and colourless fluid, between this membrane and the membrane *f*; and finally the tunica granulosa (g^1) and retinacula (g^2) present the appearance of incipient liquefaction.

141. A synopsis in my former memoir exhibited seven successive stages in the *formation* of the ovum (par. 292. *Note.*). In the present paper also, it will be convenient to adopt the same plan of considering the ovum in successive stages. These, however, occurring *post coitum*, will be stages of *development*. I propose to consider as the first stage, that represented in Plate V. fig. 93; and as the second stage, the condition which is frequent when the ovum leaves the ovary (figs. 96. and 97.).

142. To obtain these facts, and have it in my power to state them with any degree of confidence, and in the order of their occurrence, has been an undertaking of no common difficulty; and there did not exist, so far as I could discover, any recorded observations belonging to this period that might be taken as a guide.

Locality in which the Ovum is fecundated.

143. As to the particular locality in which the ovum becomes susceptible of development, physiologists are not agreed. Some maintain that it acquires this susceptibility before it leaves the ovary; others that the change is not effected until after its expulsion from that organ.

144. It is not my purpose to discuss the question whether contact of the seminal fluid with the ovum is or is not essential to impregnation. Yet perhaps it may be proper for a moment to refer to the possibility of that contact while the ovum is still within the ovary, this having been denied.

145. PREVOST and DUMAS † maintain that the Spermatozoa do not penetrate so far as to the ovary, and conclude that in all Mammals impregnation takes place in the horns of the uterus. I do not doubt that the observations of PREVOST and DUMAS were accurate, for in seventeen out of nineteen instances in the Rabbit, though the parts were generally examined while still warm, I was unable to discover Spermatozoa in the fluid collected from the surface of the ovary. In the other two instances, however, Spermatozoa, or at least animalcules exactly like those I had been accustomed to meet with in the uterus and vagina, were really found on the ovary. I should rather say, that on one of those occasions Spermatozoa were seen, while on the other it was a single Spermatozoon that was observed. Some of the former were alive and active, though not in *loco*motion; others were dead. In that case, twenty-four hours *post coitum*, there was neither enlargement of the Graafian vesicles nor a high degree of vascularity in any of the parts. In the other instance the single Spermatozoon found was dead, and the ova had escaped. Now whether the Spermatozoa are essential to the impregnating power of the seminal fluid, I do not think it needful to inquire. The fact that in the course of these researches they have been met with on the ovary, demonstrates that the seminal fluid sometimes penetrates as far as to the surface of that organ. Whether it penetrates into its interior I am unable to determine; but certainly the changes above described, as taking place *post coitum*, in the condition of the ovum while still within the ovary, are too remarkable not to favour the supposition that it does ‡.

146. The changes now more especially referred to will presently be seen. The germinal vesicle *ante coitum*, after the formation of the yelk has begun, is situated in the centre of the latter. From that locality it passes to the surface of the yelk, the germinal spot being situated on the internal surface of the germinal vesicle. The ovum (as shown on a former occasion, *l. c.* par. 85.) is conveyed from the centre to the surface of the Graafian vesicle, and indeed to that part of the surface which is situated nearest to the exterior of the ovary §, being determinately held by the retinacula in this situation ‖. The proper membrane of the yelk is hitherto extremely thin. Such is the condition of the mature ovum *ante coitum*; that is to say, its essential parts lie as *near* as possible to the surface of the ovum. *Post coitum*, before the discharge of the

† *L. c.*, No. 189, p. 199.

‡ Since the above memoir was presented to the Royal Society I have learnt that Professor BISCHOFF, of Heidelberg, had previously found Spermatozoa on the ovary of another Mammal, the Dog (par. 278.).

§ In repeated instances also I have found the germinal vesicle at that part of the surface of the yelk which was situated nearest to the periphery of the Graafian vesicle, and therefore as near as possible to the surface of the ovary. This accords with the observations of R. WAGNER, that in *Dytiscus marginalis*, and in some other insects, the germinal vesicle always appears on that side of the ovarian tubes which is directed towards the cavity of the abdomen. Thus in a bunch of ovarian tubes the vesicle is never situated at that part where the tubes lie one upon another. (Beiträge zur Geschichte der Zeugung und Entwickelung, p. 46.)

‖ R. WAGNER suggested that the "disc" (my tunica granulosa and retinacula) might serve to hold the ovum at the surface of the Graafian vesicle, and thus promote impregnation. (Beiträge, &c., p. 39.)

ovum from the ovary, the germinal spot passes to the centre of the germinal vesicle, and the germinal vesicle returns to the centre of the yelk. The proper membrane of the yelk suddenly becomes thickened.

147. Such alterations suggest the probability of some sudden and important change having been effected in the condition of the ovum; and moreover, that which is allowed to be its most essential part, previously as *near* as possible to the surface of the ovum, is now withdrawn as *far* as possible from that surface, by being once more removed to its centre. Nor is it to be forgotten that the proper membrane of the yelk, previously extremely *thin*, has suddenly thickened. These changes, which I have no doubt will be confirmed by future observers, render it highly probable that the ovum has undergone fecundation. The nature of the changes is such as to favour the supposition that they are produced by contact of the seminal fluid with the ovum; and we have seen them to take place within the ovary. I therefore suppose the ovary to be the usual locality in which the ovum is fecundated. Still, however, as we have reason to believe that the ovary, in some animals at least, discharges ova which are not fecundated†, this change may perhaps in some instances take place in the oviduct.

Discharge of the Ovum from the Ovary.

148. This appears to be effected in part at least, as supposed by VALENTIN, through the operation of a *vis a tergo*, the latter being produced by the exuberant growth of a reddish fleshy mass, which acts through the medium of the fluid of the Graafian vesicle. The particular structure originating that fleshy mass, I shall have occasion to refer to in connexion with the *corpus luteum* (par. 156.).

149. When describing in my "First Series" (*l. c.* par. 80–91.) the offices of the retinacula (Plate V. figs. 85, 86, 93, 96. g^2.), I stated that they appeared first to support the ovum in the centre of the Graafian vesicle, next to convey it to the periphery of that vesicle, and subsequently to retain it in the latter situation,—probably contributing also to attenuate the parietes of the vesicle at a certain part, so as to promote the expulsion of the ovum from the ovary. It remains to notice some other offices apparently performed by these structures.

150. It is the central portion of the retinacula, and not the minute ovum, that presents a surface for the operation of a *vis a tergo*. The retinacula therefore escape with the ovum (Plate V. fig. 96. g^2.); and by their long bands, and the connexion of those bands with the membrana granulosa, render the escape of that important body gradual. They also seem to afford a considerable surface for the operation of

† HAIGHTON showed that corpora lutea formed in both ovaries, although the access of the seminal fluid on one side had been made nearly impossible by obliteration of the tube *ante coitum*. Fœtuses, however, were present only on the unmutilated side. Philosophical Transactions, 1797. Dr. BLUNDELL went farther, obliterating the upper part of the *vagina, ante coitum*, and found that the coitus produced corpora lutea but no fœtuses. But we know that even sexual connexion is not necessary for the production of corpora lutea. See some excellent remarks on this subject by Dr. ALLEN THOMSON, article "Generation," in Dr. TODD's Cyclopædia of Anatomy and Physiology, pp. 465, 466.

those means by which the minute ovum is made to enter the Fallopian tube. And finally, enlarged and in a half fluid state, they appear to be the bearers from the ovary of a substance for the immediate imbibition of the ovum, and probably enter into the formation of the chorion.

151. The tunica granulosa (Plate V. fig. 96. g^1.) appears to assist in all of these offices, and especially in the two last named†.

The Corpus luteum.

152. When the discharge of the ovum from the ovary is very near, that portion of the Graafian vesicle directed outwards is seen to have been removed, so that little or nothing remains to obstruct the passage of the ovum besides the peritoneum. The peritoneum therefore appears to me to be the part that gives way last.

153. If a Graafian vesicle about to discharge its ovum be carefully dissected out of the ovarium, and so placed that the compressor may act upon it laterally, an appearance is obtained which I have represented in Plate V. fig. 95. This on a larger scale, and after the object has been ruptured by compression, is exhibited in fig. 96. Here *h* is the vesicle, which in my former memoir (*l. c.* par. 1–5. 25.) I described as the true and originally independent *ovisac*; *i* is the covering gradually acquired by the ovisac; the union of the two—according to my observations—forming the so-called Graafian vesicle. At the period now under consideration the covering (*i*) has become a thick and highly vascular mass; and with this change in its covering the ovisac itself has lost considerably in the size to which it had been distended.

154. A few hours after the ovum has been discharged, if lateral pressure be applied, there escapes from the thick and vascular mass (*i*) a minute translucent body (Plate V. fig. 98.), perfectly spherical in form, and having a diameter of less than half a line. This, placed under the microscope, is found to be the *ovisac*, thus easily removed from its covering. In the substance of the latter it will be remembered lie the vessels. The ovisac itself presents no trace of any, though in some instances its substance has seemed to be pervaded by pellucid points. At a certain part of it (see the figure) is the orifice by which the ovum was expelled, its margin bloody. I have found that orifice in several instances to be elliptical, and to measure from $\frac{1}{4}'''$ to $\frac{1}{3}'''$ in length.

155. Several days after the ovum has escaped, there is protruded from the centre of what was formerly the Graafian vesicle, a mammillary process, noticed by several observers, very accurately figured by De Graaf, apparently mistaken by Cruikshank‡ for the ovum (par. 129.), and not inappropriately compared to a sort of hernia by Coste. The primitive ovisac is at this later period no longer met with in the ovary§,

† Von Baer mentions that in the Dog the "disc" passes with the ovum into the Fallopian tube. (Lettre sur la Formation de l'Œuf dans l'Espèce humaine et dans les Mammifères, Commentaire, p. 40.)

‡ *L. c.*, p. 206, third day after the coitus, Experiment xviii. "The pouting part I believe is the ovum, and stands upon the top of corpus luteum. It is very vascular, particularly at its basis." See also Experiment xxiv.

§ Whether in the interim the ovisac has been absorbed *in situ* or first expelled, I do not know. In the Hog I have found what seemed the remains of ovisacs in the infundibulum.

for the mammillary process appears to consist solely of an inverted portion of the vascular and spongy substance which previously constituted the covering of the ovisac.

156. The obvious conclusion from these observations is, that *the covering of the ovisac* (Plate V. figs. 95 and 96. *i.*) *becomes the corpus luteum.*

157. In making this assertion I am so unfortunate as to find myself again expressing an opinion at variance with that of BAER. I have no doubt that the *corpus luteum* forms in the structure where he exhibits it†; but that structure, I must respectfully maintain, is not, as he calls it, the inner membrane of the Graafian vesicle; for that inner membrane is constituted by the ovisac, which disappears. Dr. POCKELS‡ has figured three membranes as entering into the formation of an advanced Graafian vesicle, besides the membrana granulosa; and it appears to me that what he has termed the "Nucleus," "Ovum Graafianum," and "Folliculus," is my *ovisac*,—a structure which it will be remembered was in my former paper followed upwards from the minuteness, in some instances, of $\frac{1}{100}$dth of a line. And it farther appears to me to be this same vesicle (the ovisac) that Dr. POCKELS refers to in the Sheep and Goat, as remaining in the incipient *corpus luteum* eight days and more after the expulsion of the ovum from the ovary§. VALENTIN‖ has very accurately shown the appearance of the *substance* of the *corpus luteum* on a small scale.

Disappearance of Ova post coitum.

158. During the rut, as already mentioned, several Graafian vesicles seem to be prepared by enlargement and vascularity for discharging their contents, besides those from which ova are actually expelled; so that for some hours even *post coitum* it is not easy to distinguish the latter from the former. After the ova have been discharged, therefore, the ovary often presents several Graafian vesicles, which are enlarged and highly vascular. These, as well indeed as many of the minuter ones, seem to be absorbed; and during several stages of that process appearances occur which it may be worth while to mention, as from their resemblance to some of the changes produced by impregnation, they are calculated to mislead.

159. The yelk liquefies. This change is first seen *around the germinal vesicle* (Plate V. figs. 99 and 100.), in which situation also it will be remembered the yelk-globules (vesicles) present their first appearance (par. 121. *Note.*). The germinal

† Lettre, &c., fig. xiv.

‡ MÜLLER's Archiv, 1836, Heft II. Tab. VI.

§ *L. c.*, p. 203. I am inclined to think that the membrane which, in some instances, is found lining the cavity (when a cavity exists) in the corpus luteum, is no other than the originally independent vesicle called by me the "ovisac." See Figures of the corpus luteum in the human female by Dr. MONTGOMERY (Exposition of the Signs and Symptoms of Pregnancy, &c., 1837.), who has very justly stated that it is not the inner membrane of the Graafian vesicle that becomes the corpus luteum.

‖ Dissertation by BERNHARDT, "Symbolæ ad Ovi Mammalium Historiam ante Prægnationem." Vratislaviæ, 1834, fig. xxx.

vesicle collapses, generally becomes elliptical, and more or less thickened (fig. 101. *c.*). The germinal spot appears breaking up, and in its centre is sometimes seen a dark point (fig. 101. *b.*). The "zona pellucida" becomes elliptical, thin, and very much distended (figs. 100, 101. *f.*). The tunica granulosa and retinacula liquefy, leaving the ovum uncovered, or with a few dark globules on its surface (figs. 99 and 100.).

160. Such are the changes observed when absorption is commencing *post coitum*. It will be seen that in some respects they resemble the earliest effects of impregnation, but differ from them in the following; viz. the germinal vesicle does not return to the centre of the yelk; the proper membrane of the yelk does not thicken, and is not even visible; and when the "zona pellucida" is distended, the imbibed fluid mixes with the yelk. The above changes also differ from those described in my "First Series" (*l. c.* par. 60. and Plate VIII. fig. 67.) as accompanying the absorption of ova *ante coitum*, in the condition of the yelk. The yelk was then described as nearly black, from myriads of minute granules and oil-like globules; while in ova absorbed *post coitum* the yelk seems to pass immediately into the state of a colourless and pellucid fluid, whether those ova are mature or immature; for I have met with some ova undergoing absorption at this period, which were exceedingly minute.

Graafian Vesicles containing Blood in their Interior.

161. After the impregnated ova have been discharged from the ovary, some of the larger Graafian vesicles, remaining unbroken, are frequently found to contain a considerable quantity of dark blood, which gives them the appearance of blackish spots. Such spots have been noticed by several authors, who supposed them to indicate the Graafian vesicles from which ova were destined to be expelled. It is not unusual, however, to find Graafian vesicles thus filled with blood in cases where the escaped ova, in number, size, and local situation in the uterus, forbid the supposition that more would have been discharged from the ovary. Of such instances I have recorded many in my notes. For example, in a Rabbit, 108½ hours *post coitum* (Table, par. 313.), ten ova were found distributed throughout the two uteri, having a diameter of $\frac{1}{4}'''$ to $\frac{1}{2}'''$, in the nineteenth and other stages. That a discharge of more ova had been destined, is not at all probable; yet in that instance,—besides the incipient corpora lutea, corresponding in number to the discharged ova,—each ovary presented several large and unbroken Graafian vesicles filled with blood (par. 125. 126.).

Ovisacs found in the Infundibulum.

162. On one occasion, with a high degree of vascularity in all the parts, I found in an ovary of the Hog three ruptured Graafian vesicles, with four apparently on the point of bursting†. Bloody strings of a fleshy substance were hanging at the orifices of two out of the three ruptured Graafian vesicles; and in the infundibulum of this side there were several of the same kind of bloody masses, of a string-like form, sug-

† None of them were distended beyond a moderate size, and they seemed to be in a healthy state.

gesting the idea of their having been rolled†. In the other ovary two Graafian vesicles were ruptured, having strings of the same kind of bloody substance pendent at their orifices. In the infundibulum of this side were portions of blood-vessels.

163. Some of the string-like masses found in the infundibulum, as well as those pendent at the orifices of the ruptured Graafian vesicles, on being examined with the microscope, presented the following parts, viz.

1. A multitude of elliptic vesicles, varying in size from about $\frac{1}{40}'''$ and less to $\frac{1}{4}'''$, of a greyish colour, and more translucent than the mass in which they lay imbedded.

2. A fleshy mass saturated with blood, in which these vesicles were found, together with portions of large and empty vessels.

3. Shreds of ovisacs, not presenting the same vascular appearance.

164. One of the vesicles just mentioned is represented in Plate V. fig. 102. It was obviously an ovisac in the course of being absorbed. At *g* are its peculiar granules, or rather vesicles, in an altered state. In the interior of each of them is another vesicle, containing a colourless and brightly pellucid fluid, and surrounded by granules. This inner vesicle is the former nucleus in an altered state (par. 297.). At *f* is the membrane, which unaltered is highly transparent, and very thick. It has become distended, wrinkled, and very thin. The yelk (*d*) seems to have passed into a fluid state; *c.* is the germinal vesicle, thickened, and probably double; and *b.* the germinal spot, having a pellucid centre. Here incipient absorption is seen to have produced the same effect upon several parts as impregnation and maceration.

165. The presence of such objects in the infundibulum appears to be not unfrequent in the Hog. I have observed them also in the Cat. To explain the occurrence of ovisacs in the infundibulum, I suppose the rupture of a large Graafian vesicle sometimes to involve the discharge of many minute ovisacs, which escape from the ovary in consequence, and are probably absorbed. I now return to the ovum of the Rabbit.

The Ovum after it has left the Ovary.

166. The diameter of the Rabbit's ovum, when it leaves the ovary, does not, according to my observations, generally exceed $\frac{1}{16}$ of a Paris line, and in some instances it is still smaller. This extreme minuteness renders its discovery very difficult. It is, therefore, important to determine the time when the expulsion usually takes place (par. 128.), for we thus obtain some notion of the distance in the Fallopian tube to which the ova have advanced. And though in different individuals this distance in a given time may not be constantly the same, still even a general idea of it is of no small advantage. We thus diminish that extent of surface, to examine which, in quest of an object so minute, long appeared to me an almost hopeless undertaking. I trust that future observers, through the Tables of observations to be subsequently

† In connexion with the *rolled* appearance of these masses, I would refer to the muscular state at certain periods of the middle coat of the infundibulum.

given (par. 319.), will be spared in some degree the fruitless labour which, in the absence of such information, it was my misfortune to bestow. An experienced eye may also infer from the condition of the discharged Graafian vesicles or incipient corpora lutea, whereabouts the ova lie. I have already stated that all the ova are discharged from the ovary at about the same time. They are, therefore, in most instances found very near together while in the Fallopian tube; so that if a single ovum be obtained, it may be presumed that the rest are not far off. The Table (par. 319.) shows that I have often found ova at the commencement of the uterus, that is within an inch or half an inch of the Fallopian tube. They seem stationary in that locality for some time.

The size of the minute Ovum no criterion of the degree of its development.

167. The figures in Plates VI. and VII. illustrating "*stages*," I have thought it proper to draw on fixed scales, scrupulously copying nature in regard to size. If however, these figures be referred to, the not uninteresting fact will be made evident, that there is no fixed relation between the size of the entire ovum, and the degree of development of its most essential parts. An extraordinary instance of this is afforded in Plate VII. fig. 124. where in an ovum of less than $\frac{1}{3}'''$ the embryo had attained a stage far beyond what is usual in ova many times as large (par. 218.). On the other hand, Plate VI. fig. 110. presents an instance in which development (as compared for example with that of the ovum fig. 113.) appeared to have been retarded.

168. Nor do any two parts of the ovum necessarily keep pace with one another; a fact well shown in Plate VII. fig. 124., where the incipient umbilical vesicle ($bb^{2\prime}$) and the structure *am.* are very far behind the embryo in the degree of their development.

169. In the following description therefore of successive stages, it will not in general be desirable to state particularly the dimensions of the ovum, nor minutely to detail the condition of any of its parts but those that serve to mark the stage.

Third Stage of Development.

170. When discharged from the ovary in the state exhibited by Plate V. figs. 96. and 97., the ovum was found in the following condition at the distance of one inch from the infundibulum in the Fallopian tube (Plate VI. fig. 103. α.). The germinal vesicle (c), was visible in the ellipsoidal mass that occupied the centre of the fluid yelk. The latter (d) was obscurely granulous. The proper membrane of the yelk (e) was seen with remarkable distinctness, being indeed, from its appearance as a thick black line, the most conspicuous object in the ovum. The distention of the membrane f had proceeded farther, and in the same proportion a pellucid fluid had been imbibed. The tunica granulosa (g^1) was present, but the retinacula were not distinctly seen†. Ovum $\frac{1}{10}'''$.

171. At β (fig. 103.) the same ovum is shown ruptured, to demonstrate the strength

† Traces of both the tunica granulosa and retinacula are, however, generally discernible, and often distinctly seen, at later periods.

of (*e*) the proper membrane of the yelk, which remained whole and still contained the yelk, though forced through the lacerated membrane *f*. The great thickness of the latter is seen in this figure; as well as the effect of pressure on (g^1) the half fluid tunica granulosa.

Fourth Stage of Development.

172. In Plate VI. fig. 104. *α*. is represented an ovum of forty-one hours, and measuring $\frac{1}{15}'''$, found about an inch from the infundibulum in the Fallopian tube. The tunica granulosa was not distinct. Around the thick, transparent membrane *f* was a dark circle (*cho*) which at first seemed the outer surface of that membrane, now exhibiting a high refracting power. The yelk (*d*) was obscurely granulous, and the germinal vesicle no longer seen†. At fig. 104. *β*. is another ovum of the same Rabbit found further advanced into the tube, and here represented after being crushed. This ovum presented the same dark circle (*cho.*) seen in fig. 104. *α*. On crushing the ovum, however, I found the dark circle to be *a thin membrane closely investing the thick transparent membrane f*. Pressure produced the following changes in that ovum; viz. The yelk-ball, *e*, (fig. 104. *α*.) became distended so as nearly to fill the membrane *f* (fig. 104. *β*.); the membranes *e* and *f*, then bursting, discharged their contents, which are seen lying between the membranes *f* and *cho*. No trace of fibres was observed in the membrane *cho*. On being crushed, it not only enlarged, but became elliptical, and bore very considerable pressure before being ruptured. This membrane (*cho.*) appears to be the chorion, which we shall subsequently find to become villous in the uterus (par. 222. 223.). It exhibits no small degree of elasticity.

Fifth Stage of Development.

173. The ovum seen in Plate VI. fig. 105., is one of 35¾ hours, and measured $\frac{1}{10}'''$. It was found near the middle of the tube. The thick transparent membrane *f* had more refracting power than in previous stages, and *asperities were observed on its outer surface*; that which previously seemed to constitute its external part having separated in the form of the membrane *cho.* described in the preceding stage‡. Instead of being invested, as in fig. 104. *α*., by a comparatively thin membrane, the membrane *f* was surrounded by a substance having a gelatinous appearance. The outer surface of this gelatinous looking substance, however, appeared to be constituted by the same

† I have met with an ovum of twenty-three hours (in the Fallopian tube) differing from the one now under consideration, in there being within the yelk-ball (*e*) several large vesicles occupying the situation of the ellipsoidal mass in fig. 103. *α*., and surrounding a vesicle (germinal vesicle?) apparently having an opacity (germinal spot?) within it. These vesicles were contained in an obscurely granulous and fluid yelk.

‡ Plate IX. fig. 153. represents the mode of origin of the chorion. The ovum seen in this figure was one of seventeen hours, and found with five others near the middle of the Fallopian tube. It measured about $\frac{1}{10}'''$. The chorion (*cho.*) was rising from the thick transparent membrane ("zona pellucida") *f*, and surrounded by what remained of the granules (vesicles) of the tunica granulosa. The chorion was thus in a stage between the stages represented in Plate VI. figs. 104 and 105, while the interior of the yelk-ball (*e*) was less advanced than that in fig. 104. *α*., the germinal vesicle being still seen (par. 168.).

membrane (*cho.*) which in the last stage closely invested the membrane *f*. If an ovum of the present stage (fig. 105.) be crushed, the membrane *cho.* presents a sensible degree of thickness, and the fluid (f^1) lying between that membrane and the thick transparent membrane *f* is found to have no small consistence. The yelk of the ovum seen in fig. 105. did not present an appreciable difference from that in fig. 104.

Sixth Stage of Development.

174. An ovum of $\frac{1}{8}'''$ found with that just described (Plate VI. fig. 105.) is exhibited in fig. 106. The membranes *cho.* and *f* were in very nearly the same condition as those in the ovum fig. 105. The membrane *e*, however, of fig. 105. had disappeared (by liquefaction) in the ovum fig. 106, and there no longer existed a granulous yelk, as at *d* in fig. 105†. In the ovum fig. 106, the thick transparent membrane *f* ("zona pellucida") was filled with a transparent and colourless fluid (*d*) which it may be proper to designate the yelk. The centre of this fluid was occupied by four large vesicles. These vesicles were spherical, but somewhat flattened. They had a very high refracting power, and being exceedingly transparent, the contour of the remoter ones was distinctly visible through those nearer to the eye. Their contents appeared to be a fluid and granules. Some of these vesicles presented in their interior a minute pellucid space, which may possibly have been a nucleus‡.

Seventh Stage of Development.

175. In an ovum somewhat larger, found in the Fallopian tube, a new set of vesicles (Plate VI. fig. 107.) had arisen, more numerous and smaller than the last, their appearance in other respects being the same. They also occupied a similar situation. The membranes of this ovum, not differing except in size from those of the ovum last described, have not been represented in the present figure.

Eighth Stage of Development.

176. In another ovum from the Fallopian tube, the vesicles in the centre of the ovum (Plate VI. fig. 108.) were found still more numerous and still smaller; in other respects not differing from those in figs. 106 and 107. The membranes of the ovum were in a state very closely resembling that of the corresponding parts in fig. 106.

177. The ovum probably passes through stages, which, in both the size and number of its central vesicles, are intermediate in reference to that I have endeavoured to re-

† The term "yelk"—as applied to the contents of the ovarian vesicle of Baer—has not been discontinued in this memoir; but from the facts recorded in it—and more particularly from the changes delineated in Plate VI. figs. 105½. 106. 107 and 108.—I am disposed to question the analogy which this term implies (par. 122. and *Note*. 318$_2$).

‡ Later observations strengthen this supposition, and enable me to extend it to vesicles in the succeeding stages. The nucleus was very distinct in each of the two vesicles occupying the centre of the ovum in fig. 105½, a stage obviously between my "Fifth" and "Sixth," but not met with in time to be described in its proper place. The pellucid nucleus, however, in all of these vesicles, seems to be present during a certain period only of their existence (par. 315 to 317.).

present in fig. 108, and the condition to be next described. The figures given, however, will suffice to show the nature of the process, which may, perhaps, be analogous to that observed by Pouchet† in the ovum of a species of Limnæus. Possibly also, the divisions and subdivisions first noticed by Prevost and Dumas in the ovum of the Frog, and now known to occur in the ova of other Batrachian Reptiles, as well as in those of certain Fishes, may be referable to a process of the same kind‡ (par. 307. 318.).

Ninth Stage of Development.

178. An ovum of sixty-three hours, and of $\frac{1}{7}'''$, is represented in Plate VI. fig. 109. It was found in the Fallopian tube within about an inch of the uterus. The vesicles seen in the centre of the ovum—still minuter than those in fig. 108, and much more numerous—had ceased to be transparent, and were punctate from dark globules, apparently on their outer surface. The vesicles were nearly of equal size, and measured each about $\frac{1}{100}'''$. The structure formed by those vesicles presented a curious resemblance to a mulberry. In the ovum, fig. 109, this mulberry-like object had a diameter of $\frac{1}{45}'''$. The membrane *f* was irregular in its thickness, and at one part had become very thin (par. 190.). Plate VIII. fig. 128. represents the same ovum crushed. The chorion (*cho.*) became elliptical (pars. 172. 222.), a change in form not participated by the membrane *f*. The contents of the ruptured membrane *f*, proceeding no farther than the dotted line, showed this to be the inner surface of a thick membrane—the chorion—which (inner surface) had been concealed by an equal refracting power in the fluid f^1. The fluid f^1 in this instance had a tinge of yellow.

179. Von Baer found a little body in the uterus of the Dog, near the tube, which seems to have been an ovum in a state resembling that of the above. He describes it as consisting of a minute central sphere which was opake, with a transparent halo or periphery. The central sphere (my mulberry-like structure?) he conjectures may have been the vitellus or future intestinal sac, and the periphery he supposes was the "membrane corticale."

Tenth Stage of Development.

180. Seven ova, one of which is exhibited in Plate VI. fig. 110, were found in the Fallopian tube within about three quarters of an inch of the uterus. The mulberry-like structure measured $\frac{1}{50}'''$, presented a greater number of vesicles—which were still somewhat smaller than the last—and the interior of its vesicles was more distinct. Their increased transparency seemed partly referable to the absence of dark globules seen in the preceding stage. Having a high refracting power, their outline was extremely well defined and sharp; more so than I have been able to represent it with a pencil. Within each vesicle was seen an object§ resembling the "germinal vesicle-

† Froriep's Notizen, No. 138, Julii 1838.

‡ Schwann has suggested that the divisions in question in the ovum of the Frog, may, perhaps, be reducible to a "cell"-formation (*l. c.* pp. 61, 62.).

§ In one instance two of such objects were observed in the same vesicle (par. 317. *Note.*).

like nucleus" observed by VALENTIN† in "globules" from various parts of the nervous system. This object was round, colourless, and pellucid, and contained a central dark point, resembling the "corpuscle" of the above author. The chorion (*cho.*) was distinguishable from the fluid f^1. Plate VIII. fig. 130, exhibits another of the seven ova crushed. The membrane *f* is here seen distended and ruptured under the compressor. The mulberry-like object—when crushed—not only filled the cavity of that membrane, but a part of it escaped, and its vesicles became pressed together into figures of several sides. The nuclei remained unaltered: their dark central points (nucleoli), however, in this instance had the appearance of globules. In the space between each vesicle and its nucleus, and chiefly *around the latter*, were now seen granules. Many of those granules, escaped from ruptured vesicles, are represented in the figure, lying in contact with the chorion (*cho.*).

The importance of examining Ova from the Fallopian Tube.

181. CRUIKSHANK‡ found ova of the Rabbit in the tube, and we are indebted to him for very important information regarding their minuteness; but the microscope in his day was not in a state to admit of his seeing their internal structure. His figures therefore are mere specks.

182. There exists another representation of an ovum of the Rabbit (and I believe only one) taken from the Fallopian tube. It is contained in a paper by T. WHARTON JONES§. That ovum was one of "the third day," found with five others in the tube "near where it enters the horn of the uterus," and in size ("$\frac{1}{70}$th of an inch") appears to have been between those which I have represented in Plate VI. figs. 109 and 110. My observations corroborate those of the author just mentioned in reference to the *appearance* of the envelope in ova of this period, but they do not agree with his views as to its real nature. T. WHARTON JONES‖ describes this envelope as "a thick gelatinous matter." In all the ova I examined, the outer portion of the envelope was already in the condition of a formed membrane, which condition it had from the first retained (Plate VIII. fig. 128., Plate VI. fig. 110. *cho.*). (The previous existence and mode of origin of that membrane I have already shown in Plate VI. fig. 104. α. and β. and in Plate IX. fig. 153.). In reference to the interior of ova of this period, my observations do not enable me to corroborate those of JONES; who remarks¶ "the granulary matter of the yelk was coherent." (Contrast with Plate VI. fig. 105½ to 110.)

183. PREVOST and DUMAS†† found no ova of either Dogs or Rabbits in the Fallopian tube, and the smallest ova they saw in the uterus measured ½‴. COSTE‡‡ has not figured an ovum from the tube in any animal. This author remarks§§, "after conception, we have stated, the vesicle which we know to be the analogue of the vesicle of

† Ueber den Verlauf und die letzten Enden der Nerven, figs. 51, 52, 70. 1836.

‡ *L. c.* § Philosophical Transactions, 1837, Part II. plate xvi. fig. 1.

‖ *L. c.* p. 339. ¶ *L. c.* p. 339. †† *L. c.* ‡‡ Embryogénie Comparée. §§ pp. 109, 110.

PURKINJE, dissolves, and the ovum *then* presents itself under the aspect of a *crystalline vesicle perfectly homogeneous.* The space which was occupied by the yelk, the condensation of which has served to form the blastoderma, is filled with a transparent fluid." With this statement I would contrast nine stages of the ovum of the Rabbit from the Fallopian tube (Plate VI. figs. 103—110). VON BAER† has figured one ovum from the Dog, found in the Fallopian tube. It would not, perhaps, be fair to contrast this with ova from the Rabbit; but the Professor certainly came prematurely to the conclusion that "in their passage through the tube the ova of Mammalia undergo scarcely any metamorphosis at all." I refer to Plate VI. figs. 103—110. in proof that there is at least one of the Mammalia to which this statement is inapplicable. Does the Dog differ so widely from the Rabbit, that in the tube its ova undergo scarcely any change?

Eleventh Stage of Development.

184. A layer of vesicles (Plate VI. fig. 111.), in all respects of the same kind as those constituting the mulberry-like appearance before mentioned, had now been added. This layer—resembling an epithelium—lined the membrane *f*, which it will be remembered had been the thick transparent membrane, or "zona pellucida" of the ovarian ovum. The mulberry was still in the *centre* of the yelk.

Twelfth Stage of Development.

185. The mulberry-like structure (Plate VI. fig. 112.) was on its way from the centre to the surface of the yelk. (The chorion (*cho.*) in this instance was distinguishable from the fluid *f'*.)

Thirteenth Stage of Development.—The true Germ.—The so-called "Serous Lamina of the Germinal Membrane" a Structure of subordinate importance.

186. In this stage the mulberry-like structure (Plate VI. fig. 113.) has reached the surface of the yelk; its own vesicles on one side, as well as some of those of the peripheral layer, have disappeared, and a vesicle contained in the mulberry-like structure comes into view. This vesicle lies in close contact with the membrane *f*. It is flaccid, and in its present situation appears flattened and elliptical. It contains a fluid and dark granules, and highly refracts light, which seems partly owing to the presence of those granules in considerable quantity on its inner surface. In two instances this vesicle measured in its long diameter about $\frac{1}{30}'''$; in another instance rather less. In the centre of the fluid of this vesicle is a spherical body (*bb*), yellowish brown in colour, and composed of a substance having a finely granulous appearance, which is distinctly circumscribed. It has a cavity in its centre containing a colourless and brightly pellucid fluid. This hollow spherical body seems to be the true germ. It measured in the present instance (fig. 113.) $\frac{1}{25}'''$; its central cavity

† Lettre, &c., fig. 3. III. and III*.

less than $\frac{1}{100}'''$. I have seen the stage now before us in a considerable number of ova measuring $\frac{1}{8}'''$ and $\frac{1}{7}'''$ †.

187. Authors on the ovum of the Bird describe their "primitive trace" of the embryo as originating in that which has been denominated the "central, thickened part of the germinal membrane." In the mammiferous ovum now under consideration (fig. 113.) the vesicles lining the membrane *f* appear to me to represent the so-called "germinal membrane" (or what has been denominated its "serous lamina"), and the remains of the mulberry-like structure seem to correspond to that which has been considered its "central thickened part." If, however, facts to be hereafter stated should render it very probable that the foundation of the new being is that contained within the mulberry-like object, figs. 109 to 113, it will perhaps appear that this foundation is no part of any membrane. The layer of vesicles (*am.*) lining the membrane *f* (fig. 113.), with those previously constituting the external part of the mulberry-like object, we shall find to form a structure of subordinate importance—the amnion (par. 199. 200.)

Fourteenth Stage of Development.—The Area pellucida.

189. The vesicle described as contained in the mulberry-like structure, and as coming into view in the preceding stage, was no longer to be discerned in the ovum represented in Plate VI. fig. 114. In its place there was an elliptical depression (*a. p.*), filled with a colourless pellucid fluid, presenting an indistinctly granulous appearance at its margin, and containing in its centre the germ (*bb*), which had nearly the same appearance as that in fig. 113, but was somewhat larger. The elliptical depression here mentioned appears to correspond to the *area pellucida* of authors on the Bird.

Fifteenth Stage of Development.

190. The vesicles forming the outer part of the mulberry-like structure had coalesced, where in contact, with those of the layer (Plate VI. fig. 115. *am.*) lining the membrane *f*; but they still formed a projection. The membrane *f* was attenuated (par. 178.), and projected in some degree at the part where the germ was observed to lie. (In another ovum found at the same time, slight pressure caused a sort of hernia at this part, one of the vesicles in the layer *am.* protruding through the membrane *f*. This attenuation of the membrane *f* may perhaps have reference to imbibition.) The vesicles *am.* appeared enlarged or flattened, and pressed together into polyhedral forms (Plate VIII. fig. 129.), and dark globules were seen at their periphery. The interior of those vesicles was very distinct; and if the figure now referred to be com-

† Perhaps it would be more correct to consider the vesicle itself (which forms the interior of the mulberry-like structure) with the whole of its contents as the true germ. The particular period at which the formation of the germ (as such)—within the mulberry-like object—commences, my observations do not enable me to state; but in a stage apparently rather more advanced than that represented in Plate VI. fig. 108, I have seen, on the application of gentle pressure, that the mass of spherical objects, occupying the centre of the ovum, contained a fluid in its interior.

pared with Plate VIII. fig. 130 (which represents an ovum of the Tenth Stage), there will be found this difference; that in the space between the membrane of each vesicle and its nucleus there are seen in the present instance (fig. 129.) a number of dark globules, not present as such in the earlier stage (par. 180.).

191. Von Baer appears from his description† to have met with ova of the Dog in either this or a neighbouring stage; though certainly no drawing given by that eminent observer enables me to recognise the resemblance. He mentions having observed a mass of granules, which was conical in the minuter ova, and in those more advanced discoid in its form.

Sixteenth Stage of Development.

192. The layer of vesicles *am.* in the ovum Plate VI. fig. 116, appeared to be passing into the condition of a membrane. Those parts of that layer which formed the *sides* of the area pellucida (*a. p.*) were raised and approaching one another, while at the ends of that pellucid space there was no such tendency, but, on the contrary, the appearance of depression into a sort of channel. The sides, here seen to have been in near approximation, appear subsequently to come into contact and unite (Plate VII. fig. 121 D.). (If this supposition be correct, Plate VII. fig. 122—representing a much later stage—shows this union to have taken place at one point; and in figs. 121 A. and 121 B. the union has been more extended. In fig. 122. there is seen a circular space on each side of the point of union. These circular spaces seem to represent the parts which in the sixteenth stage had the appearance of being depressed into a sort of channel, or in other words, exhibited no tendency to become raised over the area pellucida).

Seventeenth Stage of Development.—Central and Peripheral Portions of the Germ.—Origin of the Lamina subsequently vascular.

193. About this time the germ separates into a central and a peripheral portion. In the figure representing the present stage (Plate VI. fig. 117.) the ovum is seen in profile, and the germ therefore is not visible. (An idea may be formed of the separation here mentioned from Plate VIII. fig. 148, in which bb^1 is the central, and bb^2 the peripheral portion of the germ‡.)

† Lettre, &c., p. 12.

‡ The germ is here represented in its vesicle as seen while still in the centre of the ovum. (The mulberry-like structure was imperfect, and hence the possibility of seeing the objects in its interior.) In this instance the incipient separation of the germ into a central and a peripheral portion appeared to have been premature. These central and peripheral portions of the germ are represented in Plate VII. figs. 121 A. 121 B. and 122. bb^1 and bb^2. Whether they really arise from a separation of the object *bb* (Plate VI. fig. 113 to 116.) into two portions, future observation must decide. Possibly the object *bb* disappears by liquefaction, and a linear trace, corresponding to the "primitive trace" of authors on the Bird, arises in its place. In either case, however, the terms *central* and *peripheral portion of the germ* will be useful in the present memoir, and in either case the embryo does not arise in the substance of a membrane.

194. Before mentioning the most remarkable feature in this ovum, I would refer to the opinion generally received at present regarding the manner of origin of the "mucous lamina" of the so-called "germinal membrane." This, however, has hitherto been the subject of conjecture only, as will be amply shown by the following extract, containing perhaps the latest that has been written on the subject; and it comes from a very high authority, that of RATHKE †.

"PANDER, BAER, and I,—the former in reference to the Chick, I in reference to the Crafish,—have used the expression that it [the mucous lamina] separates by splitting from the serous. We thus gave it as our opinion, that this process consisted in the splitting of the germinal membrane. More recently BAUMGÄRTNER has expressed doubts of such an origin of the mucous lamina, and advanced the opinion that it becomes deposited upon the serous lamina, by the latter exercising an attractive influence upon the yelk, which determines single parts of the same to arrange themselves densely on it (the serous lamina) to form a new structure [the mucous lamina]." The Professor, after stating his objections to this opinion of BAUMGÄRTNER, says there are only two ways conceivable in which the mucous lamina can arise, viz. it is either thrown off by the serous lamina, or originally there exists a single mass which splits into the serous and mucous laminæ. In order to obtain a solution of this question, he again examined the ovum of the Crafish; but as that did not satisfactorily furnish it, he concludes that it would be advisable again to examine the ovum of the Bird.

195. We thus see that there is still great uncertainty as to the manner of origin of the "mucous lamina" of the so-called "germinal membrane." I have no speculations to offer on the subject, and shall do little more than refer to figures in which it has been attempted to represent nature in ova of one of the Mammalia.

196. From the region occupied by the germ, there extended in the ovum representing the present stage (Plate VI. fig. 117.) a hollow process ($bb^{2'}$) consisting of *exceedingly pellucid* objects, which hung loosely together, and were somewhat depressed where in contact. This process seemed to pass through the central part of the now flattened mulberry-like structure, before described, and to be connected with the germ. In what manner it was so connected my observations on that ovum do not enable me with certainty to state; but later stages show it (the process in question) to enter into the formation of a structure ($bb^{2'}$) *continuous with* that which I have called the peripheral portion of the germ (bb^2 in several figures of Plate VII.). In later stages this hollow process attains a size sufficient to line the cavity, the centre of which it occupied in the ovum, fig. 117; and probably in proportion as this process widens at its origin, the remains of the former mulberry-like structure disappear. Provisionally I may perhaps be permitted to consider the process in question as an incipient state of the umbilical vesicle. Should it prove to be so, its mode of origin must be very different from that which has hitherto seemed the most probable to authors on the ovum of the Bird (par. 194,). The pellucid objects which hang together and constitute

† Zur Morphologie Reisebemerkungen aus Taurien, p. 104, 1837.

the principal part of the process in question, appear, however, to be the foundation of, not the *mucous*, but the *vascular* lamina of the umbilical vesicle; which latter, therefore, according to my observations, is the first of those two laminæ coming into view. The observations by RATHKE† on the Crafish, above referred to, seem to me to contain internal evidence corroborating the description I have just given. Thus he mentions a layer of minute albuminous granules as present on the inner or yelk surface of the germ, soon after it has arisen, these granules being in some parts very loosely connected among themselves. Still more in accordance with my observations on the origin of the umbilical vesicle in Mammalia, are those of the same eminent author in a former series of Researches‡, on the first trace of the subsequent posterior half (that is the abdomen) of the Crafish. This structure, according to RATHKE, presents itself as a *little sac, finely granulous in its substance, issuing from the bottom of a depression existing at the surface of the yelk.*

Eighteenth Stage of Development.—First Change in Form presented by the Germ.

197. In Plate VII. fig. 118. *bb*[1]. the central portion of the germ presents a pointed process (par. 213.). In previous stages the germ had a finely granulous appearance, and was comparatively pale in colour. In the ovum now before us (fig. 118.) the central portion of the germ was nearly black, apparently from globules of extreme minuteness. It seemed distinctly circumscribed, and contained a pellucid cavity in its larger end. It measured in length $\frac{1}{30}'''$. (The embryo in its most incipient state is subject to considerable variation in both its form and the appearance of the globules of which it is composed. Of this an instance is afforded in fig. 121 D.)§

198. A dark object, represented in the middle of the same figure (fig. 118.), appeared to line part of the inner surface of the ovum. That object was so obscured by blackish globules that I remain in entire ignorance of its structure; and having seen but a single ovum which in reference to the object in question was in that particular condition, I am equally incapable of stating in what manner it arose. The process (*bb*[2]) described in the preceding stage was discernible, and the dark object in the present figure may possibly have been situated in the interior of that process. We shall find apparently the same object to present itself in later stages (par. 203—206.).

199. The stratum of vesicles *am.* (fig. 118.) had passed into the condition of a membrane, and the space containing the germ had become more defined. The cause of the latter change appears to be the following; which, however, is offered as no more than probable, as my observations do not extend to a period sufficiently advanced to admit of certainty. That portion of the membrane *am.* (see the figure, and more particularly in later stages, figs. 121 A, 121 B, and 122) which surrounds the germ sinks

† Zur Morphologie, &c. p. 106.

‡ Ueber die Bildung und Entwickelung des Flusskrebses, pp. 12, 13.

§ See that portion of the Note to par. 193. which relates to the possibility of the object *bb* (Plate VI. fig. 113 to 116.) disappearing by liquefaction.

in, while the externally adjacent portion of the same membrane (*am.*) is raised,—the part raised being double. The sinking in of the membrane *am.* around the germ, I suppose to indicate the commencement of a rising or separation of the latter from the surface of the yelk; and the elevation of the adjacent and external portion of the same membrane (*am.*) appears to me to denote the incipient formation of the amnion. To those who have investigated the development of the Bird, this will be familiar. For the information of others it may be added, that (if the explanation given by authors on the ovum of Birds be applicable to that of Mammals) the double membrane *am.*—by continued elevation—is made to arch over the embryo, and finally to meet and join. The outer lamina (of the fold of membrane raised) is then thrown off, while the inner lamina constitutes the amnion. I refer to the plates of BAER†, showing the mode of formation of the amnion in the Bird.

200. In adopting, however, the explanation which has been given of the manner of formation of the amnion in the Bird, I must be understood as maintaining—in opposition to the views of others—that the membrane so appropriated in Mammalia is no part of that structure out of which the embryo is formed (par. 187.). The membrane now referred to as forming the amnion, is that marked *am.* in Plate VI. figs. 113—117. It consists of the epithelium-like layer of vesicles (fig. 111.) on the inner surface of the membrane *f*, to which the vesicles presenting the appearance of a mulberry are subsequently added (fig. 113.), and with which they coalesce (fig. 115.) to form the membrane *am.* in later stages (see Plate VII.).

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Nineteenth Stage of Development.—Hollow Network in the Ovum.

201. The process (Plate VII. fig. 119. $bb^{2'}$.) first mentioned in the seventeenth stage (Plate VI. fig. 117.), as consisting chiefly of pellucid objects hanging loosely together, has now enlarged so as to apply itself to all parts of the inner surface of the membrane which in other figures has been marked *am.* It now constitutes a membranous hollow network‡. In Plate VIII. fig. 132 is exhibited a portion of this network highly magnified. It presents elliptical enlargements, containing a yellowish turbid fluid, and a nucleus which is spherical, colourless, and *remarkably pellucid.* Around each of these nuclei are dark globules. The pellucid objects entering into the formation of the process $bb^{2'}$ in Plate VI. fig. 117 appear to have been incipient vesicles just rising from their nuclei. It is probable, that subsequently those vesicles distend, and at the parts where they are in contact with one another, coalesce in such a manner as to make their cavities continuous. In this way the structure by distention may form the hollow network just described§.

† Ueber Entwickelungsgeschichte der Thiere. Beobachtung und Reflexion. Erster Theil, tab. ii.; also Burdach's Physiologie, vol. II. tab. iii.

‡ This ovum measured $\frac{1}{4}'''$ +. I have met with ova of $2'''$ apparently not more advanced in reference to the network (par. 167. 168.).

§ We shall hereafter find this explanation to be in accordance with Dr. SCHWANN's view of the mode of origin of capillary vessels (par. 295.), though it is another structure which is here produced.

Twentieth Stage of Development.

202. The network has disappeared (Plate VII. fig. 120.), but the nuclei ($bb^{2\prime}$) which were contained in its enlargements remain. The membrane of the network appears to have liquefied, and furrows filled with fluid mark its former situation. Some of this fluid surrounding the nuclei, points out the place previously occupied by the enlargements in the network. The nuclei have still the peripheral accumulations of dark globules, which existed while they were contained in the network.

203. The nuclei are situated on a lamina internal to them. This lamina may, perhaps, be the dark object mentioned in the "eighteenth stage," which has now enlarged so as to contain the yelk. Whether this lamina is the foundation of the mucous lamina, or whether it contributes to the formation of the lamina subsequently vascular, or to that of both, my observations do not enable me to state.

Twenty-first Stage of Development.

204. The furrows visible in the twentieth stage have disappeared; but the pellucid nuclei remain (Plate VII. fig. 121. $bb^{2\prime}$.), and are still surrounded by dark globules†.

Multiplicity of parts in a minute Ovum.

205. The ovum from which fig. 121. was taken measured $\frac{1}{4}'''$. A drawing of that ovum occupies the centre of Plate VII. (fig. 121 A.). I do not suppose, that with the condition of the future umbilical vesicle exhibited in fig. 121—and forming my twenty-first stage—the state of the whole ovum is always such as that in fig. 121 A,—because as already said (par. 168.) the parts do not necessarily keep pace with one another‡. It may, however, be desirable to mention the structures of which that ovum was composed. (In fig. 121 A. it presents the appearance of *incipient* collapse; this having been the effect of the fluid—kreosote water (par. 239.)—in which it lay when drawn.)

206. Proceeding from the exterior inwards, we find the parts of the ovum in question to be as follows; viz. *cho.* is the chorion; f^1, fluid; *d.* yelk which has escaped from its cavity, and not mixed with the fluid f^1; f, the thick, transparent membrane of the ovarian ovum ("zona pellucida"); *am.* the amnion; *am.f*, a part at which the membrane *am.* now adheres to the membrane f; bb^1, central, and bb^2 peripheral portion of the germ. Continuous with the peripheral portion of the germ is the subsequently vascular lamina of the umbilical vesicle, $bb^{2\prime}$, having a lamina internal to it. Within the part last mentioned is the yelk.

207. Thus the ovum of the Rabbit may pass through at least one-and-twenty stages of development, and—as in the ovum just described—may contain, besides the

† Von Baer has figured objects seen in an ovum of the Dog, which appear to have corresponded to the nuclei and dark globules above-mentioned. (Lettre, &c. p. 12. fig. V*.) His description of them, however, does not at all accord with my observations on ova of the Rabbit.

‡ And I have met with ova many times as large which were not more advanced in their development.

embryo, four membranes, one of which has two laminæ, before it has itself attained the diameter of half a line; one membrane moreover (denoted by the letter e in some of the figures of Plates V. and VI.) having disappeared by liquefaction in the Fallopian tube. Hence the importance of examining ova when minute. The smallest ova found by PREVOST and DUMAS in the Dog, measured half a line,—that is, rather more than the ovum I have now described. But the ova met with by those observers seemed to them to consist of *a single membrane*†. VON BAER‡ mentions ova from the Dog of the same size ($\frac{1}{2}'''$) as composed of *two membranes*, the inner having granules on its internal surface (par. 204. note). It is, however, only fair to add, that the size of minute ova affords no criterion of the degree of their development,—and also that in this respect there may be a difference in different animals; though these considerations are scarcely sufficient to explain the absence of two or three membranes. The membrane *f*—unless its presence has been ascertained from the examination of very minute ova—may easily escape notice as a separate structure in ova more advanced§.

Adhesion between the thick transparent Membrane of the ovarian Ovum and the Membrane which forms the Amnion.

208. It has just been stated that the membrane *am.* adheres at a certain part to the membrane *f* (Plate VII. fig. 121 A. *am.f.*). I have observed, that the points adhering do not constitute a complete circle or ellipsis, but are interrupted at that part which is in the neighbourhood of the caudal extremity of the embryo. Here the adhesion (at least originally) does not take place. This adhesion appears to correspond to one known to occur in Birds; and possibly it takes place in the Mammal for the same purpose as that which it is supposed to answer in the Bird, viz. to promote the

† *L. c.* No. 188, p. 182. PREVOST and DUMAS state indeed that larger ova of the Dog, viz. $\frac{3}{4}'''$ to $1'''$, consisted of a single membrane.

‡ Lettre, &c. pp. 11, 12.

§ T. WHARTON JONES (*l. c.*, p. 341. and fig. 6.) gives the following description of two ova found in the horn of the uterus of the Rabbit seven days after impregnation, and measuring about $\frac{1}{70}$th of an inch (between $\frac{1}{4}$ and $\frac{1}{5}$ of a French line) in diameter. "No vitellary membrane was to be seen. The gelatinous-looking envelope constituted the only covering of the yelk, which now formed a vesicular blastoderma. The cavity of the gelatinous-looking envelope was much larger than the vesicular blastoderma. The inner surface of the gelatinous coat presented what I supposed to be fragments of the vitellary membrane adhering to it. In both ova the vesicular blastoderma was irregular on one side, that on which I supposed the embryo was about to be developed. It was beginning to present the separation into layers, and had the same peculiar friable globular structure as the blastoderma of the Hen's egg." In reference to this description, I am compelled to state that Plate VIII. fig. 138. represents the vitellary membrane (*f*) entire, as seen by me in an ovum of $\frac{1}{70}'''$; that I have not met with any such phenomenon as the separation of a membrane into layers; and that the result of my observations on the subject of a "vesicular blastoderma"—having a peculiar "friable globular structure"—may be found in Plate VI. figs. 105½ to 117., and in Plate VII. figs. 118 and 119. *am. bb.* and *bb*^{w}; also in par. 187. 192. 199. 200., and par. 196. 198. 201. The real nature of the "gelatinous-looking envelope" has been already explained (par. 172 to 174. 178. 180. 182.).

rising of the membrane *am.* for the formation of the amnion (par. 199.). In Plate VIII. fig. 145. is exhibited an ovum drawn after it had lain six weeks in dilute spirit. The membrane *am.* (with its contents) is here seen to have been pendent from the membrane *f*, through the adhesion now mentioned. Possibly this adhesion may assist to explain why the incipient embryo which it incloses, is (as I have found it) generally either uppermost or undermost when the ovum is viewed in a fluid medium. The relations of the thick transparent membrane ("zona pellucida") of the ovarian ovum in stages subsequent to that which I have called the "fifth" (Plate VI. fig. 105.), and the adhesion just described as taking place between this membrane and the membrane entering into the formation of the amnion, may, perhaps, be considered as showing the correctness of those who had conjectured the thick transparent membrane to be analogous to the vitellary membrane in the ovum of the Bird (par. 174.).

The Embryo a Congeries of Vesicles.

209. The precise condition of the embryo has not been mentioned in the three last stages; the fact being that its appearance undergoes such rapid changes, and is subject to such variation, that to have attempted to associate any particular condition of it with that of the parts representing those stages, would have been quite fruitless, and moreover calculated to mislead. Besides which, there are so many dark globules mixed with the vesicles, of which the embryo is now composed, that it is extremely difficult to ascertain what the condition of the latter really is;—a difficulty augmented by the tendency in many instances to a sinking in at that part where the embryo lies. If however fig. 118. be compared with fig. 121 A., the following differences will be observed. In the former, the central portion of the germ (bb^1) presented globules of extreme minuteness; in the latter it was a congeries of distinct vesicles, of which moreover there were two states. Those most internal were smaller and appeared nearly black; while those of the outer set were more expanded, and paler in their colour. The peripheral portion of the germ in fig. 121 A. (bb^2) was seen with great distinctness; and between the central and peripheral portions of the germ there were extended cords formed of vesicles, having the appearance and apparently performing the office of retinacula.

Stages of Development later than the Twenty-first.

210. If I have succeeded in making plain the foregoing "stages," later ones will not require to be described so much in detail. Nor is it my purpose to extend the present paper to stages in continuous succession, beyond that which I have called the twenty-first.

Progressive Formation of the Vascular Lamina of the Umbilical Vesicle.

211. The subsequently vascular lamina of the umbilical vesicle in the twenty-first stage (Plate VII. fig. 121. bb^2.) consisted of scattered nuclei, having peripheral accu

mulations of dark globules. In a stage somewhat more advanced, though in an ovum of about the same size (Plate VIII. fig. 150.), there were seen, not scattered nuclei, but vesicles pressed together into a polyhedral form, each vesicle containing its colourless and pellucid nucleus. Some of the nuclei contained a dark globule; and in the vesicles were globules, situated especially *on the nuclei* (par. 304.). As already stated, it is probably in this lamina that blood-vessels subsequently form †.

Arrangement of the Vesicles composing the Embryo, and Order of their coming into view as Vesicles.

212. A condition of the germ or embryo seen in Plate VII. fig. 121 B, appears to represent the state succeeding that exhibited in fig. 121 A; and both of these figures, it may be added, were taken from ova of the same Rabbit. The germ in fig. 121 A. has been already briefly referred to (par. 209.). If fig. 121 B. be compared with it, the following differences will be observed. In the earlier state (fig. 121 A.) the peripheral portion of the germ (bb^2) was cordate,—in the latter (fig. 121 B.) it was somewhat lyrate in its form. (In this respect, however, I have observed some variation.) In the less advanced ovum (fig. 121 A.) the central portion of the germ (bb^1) appeared to consist of two parts, an internal and an external,—while in that more advanced (fig. 121 B.) it consisted of three distinct parts,—an internal, a middle, and an external. Thus in the later stage a new part had come into view. The new part seemed to be that which occupied the most central situation, parts previously situated there having been pushed farther out. Each of the several parts or layers now referred to was so distinctly circumscribed, as to appear almost membranous at its surface.

213. More particularly compared, the two figures in question exhibit farther differences. In the less developed ovum (fig. 121 A.) the most internal object was a dark trace, enlarged and hollow at one end, pointed at the other. In the ovum more developed (fig. 121 B.) the corresponding part occupied, not the most internal, but the second or middle place. Instead of being hollow merely at one extremity, it was now a hollow tube, with an enlargement at both ends. The part which had subsequently come into view (fig. 121 B.) was at the cephalic end. This part is shown more highly magnified in fig. 121 C. It consisted of two portions, one of which was spherical, and the other seemed a process from the first. The spherical portion contained a cavity filled with a brightly pellucid fluid. The external surface of this object was distinctly circumscribed, and almost membranous. Its substance appeared granulous at some parts, and at others presented globules or incipient vesicles. At a certain part the formation of globules (vesicles) had proceeded so far as to constitute the process above mentioned; and over this process the outer membrane (if such it may be called) was continued. (This object and the changes now described will perhaps serve to convey

† Whether the lamina represented in Plate VII. fig. 121—as having the scattered nuclei lying on it—enters into the formation of the vesicles in Plate VIII. fig. 150, I am unable to determine.

an idea of the manner in which the central portion of the germ (figs. 118, 121 D. bb^1) undergoes its *first* change in form, already pointed out (par. 197.))†.

214. In fig. 122. is seen a more advanced condition of the same parts. The minute body corresponding to that just referred to in fig. 121 C. had assumed in the embryo fig. 122. a different form (resembling that of the most central part in fig. 121 A.), and in a still later stage (fig. 123.) the corresponding part had in its turn become a tube, having very much the form of that which in the embryo fig. 121 B. occupied the second or middle place‡.

215. The parts are dark in proportion as they lie near to the centre of the germ, which seems owing to the less expanded state of the vesicles of those parts, and to myriads of others which are coming into view.

216. In fig. 122. is a band of vesicles forming a sort of arch. The absence of the membrane *am.* at certain parts has been already mentioned (par. 192.), in reference to this figure as well as others. One object of the open spaces thus occasioned, may possibly be to admit of certain parts of the germ or embryo continuing in more immediate communication with the exterior than would have been the case had a membrane intervened (par. 190.); and coincident with the existence of those spaces is the fact, that the vesicles forming the peripheral portion of the germ do not make their appearance there in the same quantity as elsewhere,—while the accumulation of those vesicles at the parts over which the membrane *am.* does extend, presents the band or arch in question.—The peripheral portion of the germ (including the band or arch just mentioned), as already stated, is continuous with the subsequently vascular lamina of the umbilical vesicle. In later stages, as the central portion of the germ advances in its size, the arch in question seems to undergo a change in its situation, and to become relatively very small (par. 219. and Plate VII. fig. 124. bb^2.). Is not the peripheral portion of the germ the foundation of the heart and great vessels? (Compare, for instance, the arch above referred to in Plate VII. fig. 122. with representations by Professor SCHULTZ § of the origin of those parts in the Bird.) If so, my "peripheral portion of the germ" obviously corresponds to the "area vasculosa" of authors on the ovum of the Bird‖.

Foundation of the Central Portion of the Nervous System and of the Vertebræ.

217. In Plate VII. fig. 127. I have attempted to exhibit the visceral surface of the future central portion of the nervous system and the incipient vertebræ, in an embryo

† See the Note to par. 193.

‡ In these figures the enlargement at the lower extremity indicates the situation of the future sinus rhomboidalis. It is not intended in par. 212 to 215. to be implied that no additions of vesicles are made externally. The nature of these, however, my observations do not enable me to state.

§ Das System der Circulation in seiner Entwickelung, Tab. V. and VI. Stuttgart and Tübingen, 1836.

‖ PREVOST and DUMAS appear to have seen an ovum of the Rabbit in a state between that exhibited in my figs. 123 and 127. (*l. c.* fig. 13.). No observation of mine leads me to suppose with PREVOST and DUMAS that the Spermatozoa enter into the formation of the central portion of the nervous system; though as to the early appearance of this part, my observations to a certain extent agree with theirs (par. 312.).

which measured rather less than $1\frac{1}{2}'''$ in length. The ovum containing it was fixed in the uterus, and had a diameter of more than six lines. The period was $8\frac{1}{2}$ days. This embryo was brought into view by dilute nitric acid. The foundation of the spinal chord and its sinus rhomboidalis are visible between the two rows of incipient vertebræ. CRUIKSHANK† appears to have seen the embryo of the same animal (the Rabbit) in a condition resembling this.

An Embryo of remarkable Minuteness.—Effects of Flexion of the Embryo.

218. I have stated that within certain limits the size of the entire ovum affords no criterion of the degree of advancement of its parts. In only a single instance, however, have I met with so remarkable a proof of this as is afforded in Plate VII. fig. 124, where in an ovum of less than one third of a line, the embryo had attained a stage in its development approaching to that in another instance in which it measured many times the length. In fig. 124. the embryo was only $\frac{1}{7}'''$—or about $\frac{1}{70}$th of an English inch—in length; being thus little more than half that of the object represented in fig. 122, though the latter was beyond all comparison behind it in the degree of its development. So remarkable a deviation in point of size is probably of rare occurrence.

219. The embryo of the ovum, fig. 124, is shown more highly magnified in figs. 125 and 126. As viewed on one side it might have been compared to a sort of spoon; but on the spinal surface (of which, however, I could not obtain a direct view) it seemed in part unclosed. It was opake, had a granulous appearance, and was yellowish-brown in colour. When first seen the cephalic extremity was somewhat bent upon itself, as represented in fig. 125; and at a certain part the margin had become wrinkled. On slight pressure being applied, this extremity was observed to fall back into the nearly straight condition exhibited in fig. 126, when the wrinkles were no longer seen. The connexion of this wrinkled appearance with flexion of the embryo is interesting. The embryo had the form of a marrow-spoon. Flexion of such an object upon its hollow surface produced wrinkles at the margin. With continued flexion the wrinkles would doubtless have passed into folds. It hence appears that some of the earliest divisions of the embryo into more special forms‡, are effected by the flexion on itself above described§. The fluid in which the embryo was contained (fig. 124.) appeared somewhat gelatinous, and was in no small degree transparent, though in many parts obscured by dark globules. It seemed to be invested by a de-

† *L. c.*, Tab. IV.

‡ See figures of the embryo of the Common Fowl in HUSCHKE's paper on the first development of the eye. MECKEL's Archiv, 1832. Sechster Band.

§ Several dark globules noticed lying together at one point, perhaps indicated the incipient formation of the eye. Unfortunately the drawings are in little more than outline. The sketch, fig. 126, was not commenced until I had examined the object for a considerable time, so as to be quite sure that I understood it in all its parts; and then on beginning to draw it, I had produced only what is shown in fig. 126, when the ovum became shrunk, somewhat dried, and so much altered, that I did not venture to proceed, and no addition has been made to that drawing since.

licate membrane, which I conjecture was a part of, and continuous with, the layer of vesicles (*am.*) lining the membrane *f*†. This layer in other parts, it will be observed, was very far behind in the degree of its development (par. 168.). Such was the case also with the process forming, as I suppose, the incipient vascular lamina of the umbilical vesicle $bb^{2'}$. The situation of the latter structure was such as to confirm my views as to its place of origin. A comparatively opake object (bb^2) crossed the embryo near its middle, and prevented my seeing the latter distinctly at that part, which therefore has been represented by dotted lines. I am disposed to think that this object corresponded to the arch (bb^2) represented in fig. 122. and if so, what has been already stated (par. 216.) on the continuity of that arch with the subsequently vascular lamina of the umbilical vesicle, will be applicable here. Farther, the object bb^2 in fig. 124. occupied a situation not very remote from that of the future great blood-vessels and the heart‡.

220. The continuity already pointed out (pars. 196. 201—206. 216. 219.) between the peripheral portion of the germ (Plate VII. figs. 121 A. 121 B. 122. 124. bb^2.) and the subsequently vascular lamina of the umbilical vesicle ($bb^{2'}$ in the same figures, and in figs. 119. 120. 121; also in Plate VIII. figs. 132 and 150.), appears to me to go very far towards explaining why observers have hitherto supposed the embryo to *arise* in the substance of a *membrane*. I would ask particular attention to the following recapitulation of several of the facts recorded in this memoir; viz. The dark spot designated by Coste the "Tache embryonnaire," obviously corresponds to my "peripheral portion of the germ" (which has the central portion (bb^1) lying under, and often very much concealed by it). The germ sends forth a hollow process (Plate VI. fig. 117. $bb^{2'}$.). This process, expanding, receives the yelk into its interior, lines the membrane *am.* as a network (Plate VII. fig. 119. $bb^{2'}$. Plate VIII. fig. 132.), and passing through the stages represented in Plate VII. figs. 120 and 121, subsequently assumes the state exhibited in Plate VIII. fig. 150, which appears to be the immediate foundation of the blood-vessels and the blood. The stage shown in Plate VII. fig. 121. is repeated on a smaller scale in fig. 121 A. Here, and in figs. 121 B. and 122, the separate granules (nuclei) surrounded by dark globules ($bb^{2'}$) were seen to be a part of the layer constituted by the peripheral portion of the germ (bb^2) ("tache embryonnaire" of Coste). *External* to the structures now described is the membrane *am.* (Plate VI.

† Whether circular spaces (Plate VII. figs. 121 A. 121 B. and 122.)—such as those described as incipient in the "Sixteenth Stage" (par. 192.)—in the membrane *am.* existed in the ovum fig. 124, my observations do not enable me to state.

‡ In these Researches it has not been my practice to make drawings from recollection. Nor have I considered it sufficient to merely sketch the object while it was before me, and subsequently finish it. Precision requires that the drawings should be completed while the object is still in the field of view. On this occasion, however, from the cause above assigned, such a course was impossible; and figs. 124 and 125. were therefore not drawn until after the object had been lost. Fig. 126, as already stated, was taken while the object was still before me.

figs. 113—117. Plate VII. figs. 118. 119. 121 A. 121 B. 122. 124.), i. e. the "serous lamina" of authors, or the subsequently reflected lamina of the umbilical vesicle. *Internal* to those structures, or rather internal to the lamina of the umbilical vesicle, which is subsequently vascular, lies, when formed, the mucous lamina†.—This, I apprehend, will assist to explain why observers have hitherto supposed the embryo to *arise* in the substance of a *membrane*. It is not a previously existing membrane which originates the germ, but it is the previously existing germ which, by means of a hollow process (bb^2), originates a structure having the appearance of a membrane‡.

The Chorion.

221. When in describing the thick transparent membrane of the ovarian ovum in the "First Series" of these Researches (*l. c.* par. 52.), I stated my opinion, in unison with that of Coste and R. Wagner, "that this membrane is really the chorion of ova met with in the uterus," I had not discovered the disappearance of one membrane and the coming into view of another membrane in the Fallopian tube. Such, however, is the fact, as made known in an earlier part of the present paper (pars. 174. 172.); but it is one which did not fall under my notice until near the conclusion of these researches, notwithstanding all the pains that had been taken to procure a consecutive series of stages. It affords evidence that I was formerly mistaken in considering the thick transparent membrane of the ovarian ovum to be identical with the outer membrane of the ovum of the uterus, and "the membrana vitelli [*e*] to be still visible, and to have considerable thickness in minute ova met with in the uterus." It is not that thick transparent membrane itself (*f*) which is identical with the outer membrane, or chorion of the ovum of the uterus, but the thin lamina (Plate VI. fig. 104. α and β. *cho.*) which was seen to come into view on crushing an ovum in a certain state in the Fallopian tube. (The membrane (*e*) of the minute yelk-ball, as already mentioned (par. 174.), disappears by liquefaction during the passage of the ovum through the Fallopian tube.) Those who are practically acquainted with the various difficulties to be surmounted in this branch of physiology, will, I think, be disposed to make allowance for this error§. We are now prepared to trace the chorion through its early stages.

222. In Plate VI. fig. 103. α and β. is an ovum found one inch from the infundibulum in the Fallopian tube, at the same time that other ova in a very nearly corresponding state were met with not yet discharged from the ovarium. The next stage is exhibited in fig. 104. α, which presents an ovum taken from the same part of the

† The mucous lamina was possibly incipient in the ovum Plate VII. fig. 118; and if so, it was more advanced in that represented in figs. 120 and 121.

‡ The "tache embryonnaire," above referred to, appears to have been seen in the Rabbit by several observers. An ovum figured by Dr. Allen Thomson (Edinburgh New Philosophical Journal, vol. 9.) represents it as viewed with a low magnifying power; as does also one figured by my friend R. Wagner (Beiträge, &c., Tab. i. fig. 9.), through whose kindness I had an opportunity of seeing the object itself.

§ The membrane *f* in the present paper everywhere denotes that which was called the "chorion," and lettered *f* in my "First Series."

tube as the one last mentioned, but in another Rabbit. The membrane *f* was seen to be surrounded by a dark circle, which on the ovum being crushed, as in fig. 104. β, was found to be a thin membrane, *cho.* In fig. 105. are exhibited corresponding parts, with the addition of a fluid (*f'*) between the membranes *cho.* and *f*. This ovum consisted of *three* membranes, *e*, *f*, and *cho.* In fig. 106. the membrane *e* has disappeared, the membranes *f* and *cho.* continuing in nearly the same state as in fig. 105. The suite of observations in later stages is such as to require no explanation, for the two membranes *cho.* and *f* continue very distinctly recognizable. This will be illustrated by reference to the thirteen consecutive stages in figs. 109 to 119. Plates VI. and VII. Those drawings show that no membrane is formed outside the membrane *cho.* during the periods which they represent; and that none such is formed at later periods, up to the time when villi usually make their appearance on the surface of the ovum, I have satisfied myself by careful examination. It may be added, that the same properties characterizing the membrane *cho.* when first seen as a separate structure (par. 172.), have uniformly presented themselves in later stages, viz. great susceptibility of distention, no small degree of elasticity, and a tendency to become elliptical. These are my reasons for believing that the external membrane which becomes villous in the uterus is that which we have seen to be rendered visible as a distinct structure by crushing an ovum (Plate VI. fig. 104. β.) in a certain stage, from the Fallopian tube; a membrane denoted throughout the figures by the letters *cho.*, and designated in the present paper as the chorion †.

The Chorion becoming Villous.—Mode, Period, and Place of Origin of the Chorion.

223. An early stage in the formation of villi,—the "Saugflocken" of SEILER ‡,—is seen in Plate VIII. fig. 141. The tuft here represented measured in diameter $\frac{1}{56}'''$. It appeared to consist of vesicles containing objects having the form of vesicles. Several of such tufts are shown in profile in fig. 142. Both of these figures were taken from an ovum of $162\frac{3}{4}$ hours, and measuring $1\frac{1}{2}'''$. I have seen incipient villi on an ovum of $\frac{1}{2}'''$; and I have met with ova of $2\frac{1}{4}'''$ without any. VON BAER observed villi in the Rabbit on an ovum measuring $2'''$; while R. WAGNER on an ovum of the same size, and from the same animal, found none. Thus the period at which villi begin to form, like that of the development of other structures in the ovum (pars. 168. 169.), seems to be subject to considerable variation. The tufts on the above mentioned ovum (figs. 141. and 142.) were situated at unequal distances: some of them nearly

† Does not the structure which in the ova of oviparous animals (the Frog for instance) corresponds to the chorion of Mammalia, arise in the same manner? In many of the Invertebrata this is obviously the case. (Compare with Plate IX. fig. 153. *cho.* in this memoir, several figures in R. WAGNER's Prodromus Historiæ Generationis;—for instance, fig. II[e], V[b], V[c], X[a], XI[a], XIII[e], XVI[b].) In the latter, however, we find the chorion to arise in the ovary. T. WHARTON JONES has pointed out the resemblance in *appearance* between his "gelatinous envelope" in the ovum of the Rabbit and the ovum of the Frog (*l. c.* figs. 1, 2, and 5.).

‡ Die Gebärmutter und das Ei des Menschen, Dresden 1832, containing excellent representations of the villi of the chorion in later stages.

touching each other, many being about $\frac{1}{12}'''$ apart, and others as much as $\frac{1}{3}'''$ asunder. At the part from which fig. 142. was taken they were most numerous. The villous tufts are yellowish-brown in colour. The very first indication of the formation of villi seems to consist in a few dark globules existing scattered over the surface of the chorion.

224. The mode, the period, and the place of origin of the chorion, are subjects on which physiologists are not agreed. VON BAER† appears to suppose his "sphere creuse à paroi mince" of the ovarian ovum to become the "membrane corticale" (chorion) of ova in the uterus, though he does not express himself with certainty on the subject. COSTE‡ and R. WAGNER§ consider the thick and transparent membrane (*f*) of the ovum in the ovary to be identical with the membrane called the chorion in the uterus. PURKINJE‖, VALENTIN¶, and ALLEN THOMSON††, maintain that analogy is in favour of the supposition that the chorion originates in the oviduct. KRAUSE‡‡ conjectures that it may be formed after the discharge of the ovum from the ovary, out of the "disc" of granules (my tunica granulosa and retinacula) which surrounds the ovum in that organ. T. WHARTON JONES§§ formerly believed the "vitellary membrane"(*f*) to form the chorion, but now supposes "that the gelatinous coat ['proligerous disc'] acquired by the ovum in the ovary, and more especially circumscribed and defined after impregnation, constitutes the only covering of the vesicular blastoderma after the giving way of the vitellary membrane; that this gelatinous-looking coat forms the chorion," &c. My own observations on this subject have been recorded in preceding pages (pars. 172. 173. 221. 222.)‖‖.

225. More particularly, the following are the views of T. WHARTON JONES as to the mode, period, and place of origin of the chorion. He says¶¶, "In the ova of the Rabbit, &c. before impregnation, the proligerous disc [= my tunica granulosa and

† Lettre, &c. Commentaire, pp. 39, 40, 55. VON BAER has since expressed the opinion that in some Mammals, the Hog and Sheep for instance, this membrane arises after the ovum has left the ovary, by the secreted albumen—through a coagulation of its surface—forming for itself an investing membrane. He considers that in the Dog, however, the outer membrane of the ovarian ovum continues the outer membrane of ova in the uterus. (Ueber Entwickelungsgeschichte der Thiere. Beobachtung und Reflexion. Zweiter Theil, pp. 185 to 188, 1837.).

‡ Embryogénie Comparée, p. 80.

§ Beiträge, &c., p. 36.

‖ Encyclopädisches Wörterbuch, Zehnter Band, p. 128.

¶ Handbuch der Entwickelungsgeschichte des Menschen mit vergleichender Rücksicht der Entwickelung der Säugethiere und Vögel, p. 39.

†† *L. c.*, p. 453.

‡‡ MÜLLER'S Archiv, 1837. Heft I. pp. 28, 29.

§§ *L. c.*, pp. 339—342.

‖‖ I have in two instances observed the chorion to make its appearance at the surface of the thick transparent membrane *f* ("zona pellucida") in ova still in the ovary and apparently about to be absorbed. Maceration seems sometimes to produce a similar effect. See figs. xviii. and xxii. in BERNHARDT'S dissertation, "Symbolæ ad ovi mammalium historiam ante prægnationem," Wratislaviæ, 1834; and Edinburgh Medical and Surgical Journal, No. 128, Plate i. fig. 3, 1836, in which the transparent space surrounding the ovum appears to me to represent the fluid (*f'* in my figures) imbibed by the chorion, the latter being perhaps hidden by the surrounding granules of the "zona granulosa" (my tunica granulosa).

¶¶ *L. c.*, p. 340.

retinacula, Plate V. fig. 96. g^1. and g^2.] in which the ovum is imbedded is observed to be composed of a gelatinous substance interspersed with grains, but as yet there appears no distinctly circumscribed envelope." T. WHARTON JONES then refers to the views of KRAUSE, and remarks†, "From his [KRAUSE's] observations on the ovum *before* impregnation, he has been led to form much the same opinion regarding the origin of the chorion as is recorded in this memoir." This opinion of KRAUSE appears to have been the following‡. "It may be conjectured that the ovulum on the bursting of the folliculus passes with the disc and layer of albumen into the Fallopian tube, and that *out of the granules of the former* [i. e. the "disc"] the chorion is formed." My own observations do not realise the conjectures of T. WHARTON JONES. On the contrary, they show that when the chorion first comes into view, it is not as a "gelatinous coat§," but in the form of a thin lamina *closely investing* the thick transparent membrane or "zona pellucida" (Plate VI. fig. 104. α and β. *cho.*); and that this thin lamina—*itself the incipient chorion*—expanding from the "zona pellucida," imbibes a quantity of fluid into its interior, thickens, and with the imbibed fluid presents a gelatinous appearance,—but that the chorion is not formed out of the gelatinous-looking "coat§", since the outer portion of this "coat" is *from the first* constituted by a membranous structure, the chorion,—and the imbibed fluid which formed the principal part of the "coat" (Plate VI. fig. 105 to 113. *f'*.) soon passes into the interior of the ovum, leaving the chorion again in close contact with the outer surface of the "zona pellucida" (Plate VI. fig. 117. *cho.* and *f.*) The conjecture of KRAUSE, however, does not appear to me to coincide with that of JONES, so closely as the latter seems to have supposed. So far from this, I think it by no means improbable that—as conjectured by KRAUSE—the so-called "disc" (my tunica granulosa and retinacula) may bring from the ovary the materials out of which the chorion is formed, and it is possible that the granules (vesicles) of the "disc" may coalesce to form it. Thus that portion of the tunica granulosa (g^1) which in the ovum Plate IX. fig. 153. was seen surrounding the incipient chorion (*cho.*) on its rising from the membrane *f*, may have been destined to enter into the formation of the chorion, and to contribute towards the thickening of this membrane, as well as to supply fluid for its imbibition (par. 150. 151.)‖.

† *L. c.*, p. 340. ‡ MÜLLER's Archiv, 1837, Heft I. pp. 28, 29.

§ See his fig. 1. *l. c.* plate xvi. See also figs. 109. and 110. in Plate VI. of the present memoir.

‖ I am inclined to think that the "very delicate albuminous membrane" figured by KRAUSE (*l. c.*, Taf. I. figs. 4 to 6.) as surrounding a "thin layer of fluid albumen," must have been the incipient chorion (from some cause making its appearance in the ovary) though KRAUSE does not seem to have regarded it as such (compare with Plate IX. fig. 153. in the present memoir). On a former occasion (*l. c.*, par. 49. *Note.*) I stated that an examination of the ovum of the Goat enabled me to attest the accuracy of KRAUSE; but to a certain extent only; for I did not "in any instance find the membrana vitelli surrounded by a fluid as described by KRAUSE, but by the perfectly formed and consistent chorion" (as I then called the membrane *f.*). From this, however, it will be obvious that the "exceedingly distinct" membrane, which I found to circumscribe the yelk in ova of this animal, cannot have corresponded, as I then believed, to the thick membrane figured by Professor KRAUSE in the same situation.

225½. The names that have been given to the outer membrane of the unattached ovum in the uterus, are very numerous. That membrane appears to be the "Exochorion" of BURDACH and of VELPEAU,—the "Membrana corticalis," "Schalenhaut," and "future Exochorion" of BAER,—the "Chorion," "Eihaut" and "future Exochorion" of VALENTIN,—the "Membrane vitelline" of COSTE,—and the "Chorion" of PURKINJE, R. WAGNER, ALLEN THOMSON, and T. WHARTON JONES.

Aborted Ova.

226. Ova apparently aborted are shown in Plate VIII. figs. 133 to 135. These were found in the uterus of different individuals. At fig. 133. is one of *two* ova that were aborted, the development of others found in the same uterus having proceeded duly. I have met with three instances in which *all* the ova found in the same individual appeared to be aborted. See figs. 134 and 135. In the latter figure a vesicle, apparently corresponding to that which I have described as containing the germ (par. 186.), was seen to occupy the centre of the ovum, having a few scattered vesicles around it. This was the case in all the ova (five) found in the same uterus. In some instances of aborted ova (figs. 133 and 134.) the chorion had not made its appearance as a separate structure. In other instances (fig. 135. *cho.*) it had come into view. The aborted ova which I have met with, whether exhibiting a chorion or not, were considerably smaller than is usual in regularly developed ova of corresponding periods. In fig. 133, the yelk-ball was in the state in which I have met with it in the Fallopian tube, in early stages, except that it was much smaller and elliptical. In one instance, fig. 134, two objects resembling the ovarian retinacula were present, but the tunica granulosa had disappeared. When ova were found aborted, I generally examined the ovary, but nothing abnormal was in any of those instances observed in the ova still present in that organ. It is remarkable, that of the ova met with in these researches in the uterus, no fewer than one in about eight should have appeared to be aborted.

227. On one occasion I found six or seven vesicles in the Fallopian tube of $\frac{1}{8}'''$ (Plate VIII. fig. 136.), having a thick transparent membrane, and containing a colourless and pellucid fluid. In some instances granules were observed on their inner surface†.

Effects produced on Ova by Manipulation.

230. Ova of the Rabbit belonging to the periods chiefly considered in this paper are globular, but very little pressure renders them elliptical. The tendency to this change in form is most obvious in ova that have reached the uterus, and appears indeed to be in proportion to their size. This tendency appears to me to lie chiefly in the chorion (Plate VIII. fig. 128. *cho.*), which may be found deserving of notice. PREVOST

† On another occasion upwards of thirty vesicles were observed in the Fallopian tube, measuring from $\frac{1}{12}'''$ and less, to $\frac{1}{24}'''$. These contained also a pellucid fluid, and the larger ones had a thick membrane like that in Plate VIII. fig. 136. The membrane of the minuter ones was very thin.

and DUMAS, as well as COSTE, observed a tendency in the mammiferous ovum to become elliptical. The former also state that ova from the horns of the uterus in Dogs are at first (that is in an unaltered state) elliptical†.

Effects produced on Ova by certain Chemical Reagents.

231. The mammiferous ovum in its most interesting state being, from its minuteness, very difficult to obtain and also very perishable, it has appeared to me important to discover some medium in which, when found, its examination might be more perfectly accomplished. The smallest ova from the Fallopian tube and uterus, it is my practice to view imbedded in some of the mucus taken from those parts. The larger ova require a transparent fluid to support them. Water does not answer well. Its operation on ova of $1'''$ to $1\frac{1}{2}'''$ appears to be as follows (Plate VIII. fig. 137.): first, the inner membranes (amnion and umbilical vesicle) separate for the most part from the membrane *f*, leaving the latter on the inner surface of the chorion. This separation is produced, not by imbibition, (for the chorion does not at first enlarge,) but by the passage outwards of a portion of the fluid yelk, which now lies between the amnion and the membrane *f*. Secondly, folds appear in the chorion, their direction coinciding with the longitudinal diameter of the now elliptic (par. 230.) ovum, which soon collapses in a shell-like form (fig. 137.).

232. I have tried solutions of various chemical reagents. Some of these occasioned collapse of the chorion. Others coloured it highly, which was found a disadvantage, although that colour was transparent. Another set rendered it opake. By some it became constricted. Others caused too entire a separation of the internal membranes from the chorion. Now all of these are unfit for the purpose. We require a reagent that does not materially affect the chorion, and yet one that renders more distinct the internal objects sought for.

233. The effect of spirit of wine was found to vary with its strength. Rectified spirit (sp. gr. 0·835) acted too energetically, rendering the chorion in some degree opake. Dilute spirit facilitated for a while the examination of the interior of the ovum, by increasing its transparency‡, and the chorion remained unchanged. Considerable collapse, however, of the inner membranes followed. The dilute spirit here mentioned had a sp. gr. of 0·950, and it was of this strength when used combined with other substances.

234. Brine of common salt produced immediate and entire collapse of the internal membranes in ova of $2\frac{1}{2}'''$; the chorion continuing for a while unchanged.

235. I might go on to enumerate the effects of various other reagents, such as ether and hydrocyanic acid; the nitric and acetic acids; sulphurous acid and sulphuretted hydrogen (deoxydizing substances); solutions of various metals, among which were

† *L. c.* No. 189, p. 200.

‡ The internal membranes of minute ova which had been collapsed by water, I have observed to recover themselves on the addition of dilute spirit; but this effect appeared to be of short duration.

mercury, silver, lead, and gold; the acetate and potash-sulphate of alumine; solutions of nutgalls, and of pure tannin, as being astringent; solutions of sulphated indigo and of logwood; and lastly, aqueous solutions of chlorine and of iodine. Some of these produced interesting though unimportant results, but none of them fulfilled all the conditions above indicated.

236. The action of corrosive sublimate (*hydrargyri bi-chloridum*), as the usual test of the presence of albumen, deserves particular notice, because that after an ovum had been digested twenty-four hours in a weak solution of that salt, its transparency was unimpaired, although the internal membranes were contracted and corrugated. That ovum measured $\frac{1}{3}'''$. Another measuring $\frac{1}{4}'''$ was subjected to the action of the same salt with a similar result. Both of these ova were taken from the same individual.

237. Among the most remarkable effects, are those produced by lead and silver. The action of lead, unlike that of corrosive sublimate, seems to be upon the chorion itself, rendering it opake and white, and therefore intercepting the view of the interior. This effect was almost instantaneous. It was the acetate of lead that was employed, to which enough dilute spirit had been added to make the mixture not more than slightly sweetish.

238. Nitrate of silver, diluted with spirit as above, immediately produced the appearance of a beautiful network in the interior of the ovum (Plate VIII. fig. 140.). This was the effect of its action on the membrane of the vesicles constituting the outer lamina of the future umbilical vesicle. Very shortly, the interior of those vesicles became remarkably distinct. See Plate VIII. fig. 150, taken from an ovum of $\frac{1}{3}'''$ as seen lying in a solution of this salt. Nitrate of silver when used for the examination of the vesicles in question while still within the ovum, should be sufficiently diluted, or it will render the chorion opake. If weak, its action seems to be more perceptible upon the interior of the ovum than upon the chorion. Three ova after remaining in the above solution of silver twenty-four hours, had become of a purple brown colour; solar light having been admitted into the room.

239. I have lately chanced to see Professor JOHANN MÜLLER's paper† recommending kreosote water as a medium for preserving nervous substance, and have been induced to try its effect upon the ovum. It answers well, as will be obvious on reference to Plate VIII. fig. 138.; this drawing having been taken after the ovum had lain three days in that fluid. I recommend a saturated aqueous solution of kreosote in preference to any other medium, for the examination of the entire ovum. Its operation on ova of about $\frac{2}{15}'''$ is as follows. The inner membranes (see the figure) recede to some extent from the membrane *f*, which continues in contact with the chorion (*cho.*). The chorion generally remains unaltered in both form and size. The change, therefore, consists, not in imbibition from the exterior‡, but in the passage outwards of a portion

† MÜLLER's Archiv, 1834, Heft I.

‡ In a very minute ovum, however, immersed in kreosote water, I observed some imbibition from the exterior and consequent enlargement.

of the fluid yelk (*d*) which now lies between the amnion (*am.*) and the membrane *f*. Besides a separation from the membrane *f*, the receded membranes exhibit some separation from one another. See Plate VII. fig. 121 A. representing an ovum in which, by kreosote water, a change of this kind was produced, just sufficient to make the true nature of the interior of the ovum obvious, including the vesicles of the embryo (bb^1 and bb^2) and the nuclei composing the outer lamina of the umbilical vesicle ($bb^{2'}$), to which it imparted a slight tinge of yellow. Instead of using (as mentioned above, par. 231.) the mucus of the uterus for the examination of the minuter ova found in that organ, I have sometimes employed kreosote water in the following manner. A minute portion of this fluid having been placed upon a plane glass surface, the ovum, first freed by bibulous paper from the adherent mucus, is introduced into it, and thus examined either with or without the compressor. If the compressor be not employed, it is important by means of a very fine hair pencil to add kreosote water frequently, so as to keep the ovum from becoming dry.

240. Tar water has advantages in producing no collapse of any part. See Plate VIII. fig. 139., drawn after an ovum had lain four days in this fluid. It appears, however, to constrict the chorion, and it has the effect of colouring too highly.

241. For preserving ova I have tried several fluids. Dilute spirit and kreosote water seem each to answer pretty well; but there occurs eventually too great collapse of the inner membranes. (See par. 313. and third Note.)

Some of the earliest appearances of the Ovum.

242. In Plate V. figs. 82 to 84, are objects apparently representing stages in the formation of the mammiferous ovum even earlier than any of those met with in the "First Series" of these researches. Of the objects now referred to, which were met with incidentally, those in nearly the same stage were observed to lie together in a group. The three groups of which specimens are given in the above figures were in the immediate neighbourhood of one another, and they were all contained in a fluid substance. The most primitive of these three conditions appears to be that represented in fig. 82., in which are vesicles surrounded merely by dark granules or globules. The largest vesicle in this figure had a diameter of only $\frac{1}{100}'''$. I have seen vesicles having a similar appearance, in the same group, measuring no more than about $\frac{1}{300}'''$; and from their external appearance I am ready to suppose that they were compound, consisting of at least two membranes, the one closely invested by the other. The next stage noticed, is that in fig. 83. Here were found central vesicles having the same appearance of a compound structure as the foregoing, but being in general larger (the largest in the figure measured $\frac{1}{75}'''$), and each presenting an envelope of smaller vesicles. Among the latter were many dark granules or globules. In fig. 84. is seen a stage somewhat more advanced. The central vesicles had essentially the same appearance as the foregoing, but were generally larger (the largest in the figure was about $\frac{1}{50}'''$), and their envelopes of vesicles seemed more perfectly formed, and were

free from the dark granules or globules of the preceding stage. One of the central vesicles in this figure presented an indistinct spot. The object in fig. 81. is from the ovary of the common fowl. Its central part resembled the objects in figs. 83 and 84. from the Rabbit (par. 292. *Note.*).

Facts noticed by preceding Observers, cited to show the Accordance in various respects between the Development of Mammalia and that of other Animals.

243. I have copied from CARUS† the drawing of a structure (Plate VIII. fig. 131.) occurring in the ovum of one of the Mollusca,—*Unio tumida.* With this I would compare fig. 130. The latter represents a structure of the same kind as that which in Mammalia closely invests the embryo, and seems to enter into the formation of the *amnion*; the former exhibits an object which, in the molluscous animal above-mentioned, appeared to CARUS to be the foundation of the *shell.* The Professor saw a similar structure in ova of *Anodonta.* The "rhombick fields" in the figure from CARUS, as that author terms them, (which appear to me to have been vesicles with nuclei) seemed to *become more numerous* as development proceeded. With this observation I would compare what has been stated (par. 174 to 178. 180. 314 to 318.) regarding the greater number and smaller size of the successive sets of vesicles in the mulberry-like structure met with in several stages of the mammiferous ovum, (Plate VI. figs. 105½ to 110., Plate VIII. fig. 130.).

244. In the ovum of some of the Crustacea, there occurs a striking resemblance in appearance to the structure, just referred to in the Mammalia, when it has attained a more advanced stage. Such for instance is the case in the ovum of the Crafish, *Astacus fluviatilis*‡. Spiders present in their ova a resemblance equally remarkable. With Plate VI. fig. 114. *am.* I would compare, for example, the ova of *Epeira diadema*, as figured by HEROLD§. Now in those animals, the structure which I suppose to correspond to that marked *am.* in my figures, appears to enter into the formation of the *outer covering of the abdomen.*

245. In none of the figures of the authors last referred to, have I been able to discover any trace of what seems to me entitled to be denominated a "germinal membrane." But, on the other hand, there is to be recognised in a great number of those figures, an unquestionable similarity at the part where the embryo arises, to the corresponding part in the ovum of Mammalia.

246. RATHKE describes a depression in the ovum of the Crafish‖, and also in that of *Bopyrus squillarum*¶, which in some respects appears closely to resemble that which I suppose to be the corresponding part in Mammalia, as shown in Plate VI. fig. 114. *a. p.*

† Neue Untersuchungen über die Entwickelungsgeschichte unserer Flussmuschel, Tab. II. fig. 1.

‡ RATHKE, Flusskrebs, Tab. I.

§ Untersuchungen über die Bildungsgeschichte der Wirbellosen Thiere im Eie, Theil I.

‖ Flusskrebs, Tab. I. fig. 2.

¶ Zur Morphologie Reisebemerkungen aus Taurien, p. 44.

Of *Bopyrus* he says, "when the formation of the embryo is about to commence, there arises on one part of the yelk a minute, pellucid, and perfectly colourless spot"†. "Where this spot is, there is presented a long and broad, but very shallow depression."—"The above-mentioned colourless spot does not indicate a very great thickening of the germinal membrane, but only a space behind the external membrane of the ovum (Eihaut), which is perhaps filled with a fluid as clear as water, for after the operation of diluted nitric acid that part had not in the least lost its transparency." The same author describes in the Amphipoda‡ a "tray-like depression" as occurring on the surface of the ovum. In certain Decapoda§ (*Crangon* and *Palæmon*) he mentions "a place where the yelk to some extent is somewhat flattened, having at the same time receded, and where a disc of little thickness, consisting of a substance as transparent as the purest glass, lies upon the yelk."

247. In ova of the Actinææ, RATHKE found that *no* "*germinal disc*" *or* "*germinal membrane*" *arose* which could develope itself into an embryo; and hence concludes that here the formation of the new being must take place in a manner entirely different from that which occurs in Mollusca, Insecta, Crustacea, and Vertebrata‖.

249. The acknowledged existence of an "area pellucida,"—for instance in the ovum of the Bird,—is opposed to the present views of authors, that the embryo arises in the substance of a membrane; but it accords perfectly with the fact (Plate VI. fig. 114.), that the germ or future embryo of Mammalia is contained in such a pellucid area.

250. RATHKE in a recent paper¶, though not doubting that the "primitive trace" is constituted by the "central portion of the germinal membrane" (for he uses these terms synonymously), makes known the fact,—observed by him in Mammals, Birds, and some Reptiles,—that parts previously supposed to be formed by what BAER had denominated the "laminæ ventrales of the serous lamina of the germinal membrane," really originate independently of any membrane. These parts are the ribs and pelvic bones and the muscles of the thorax and abdomen, which, according to RATHKE, arise in a newly added substance "proceeding out of the primitive trace," and pushing the membranous "laminæ ventrales" farther and farther from the latter. Observations previously made by REICHERT†† are referred to by RATHKE as being in accordance with the above. REICHERT had found that the part originating the lower jaw and hyoid bone "grows out of the primitive trace." Now if, from the facts made known in the present memoir, it should appear that the "primitive trace" is not constituted by the central portion of a membrane, it will be easy to understand that the parts above referred to by REICHERT and RATHKE should have an origin equally independent of a membrane.

251. An appearance in the development of the Frog and Salamander has been thus

† Zur Morphologie, &c., Tab. II. fig. 1.
‡ *Ib.*, p. 74.
§ *Ib.*, p. 83.
‖ Zur Morphologie, &c. p. 15.
¶ MÜLLER's Archiv, 1838, Heft IV.
†† Ueber die Visceralbogen der Wirbelthiere, Berlin, 1837.

described by RATHKE†. "Soon after the development of the ovum of these amphibia has commenced, the germinal membrane *becomes in one part more and more thickened*, and the thickening presents itself under the form of a moderately broad lamina, extending about the distance of from one pole of the yelk to the other‡. *Around this lamina, which is the primitive portion of the embryo*, the germinal membrane becomes somewhat drawn in; and at this time the two ends of the lamina (which are the cephalic and caudal extremities of the embryo) *grow forth like two liberated processes* out of the germinal membrane, becoming at the same time curved so as to approach one another around the yelk, as it were striving more and more to embrace the latter." The "thickening" here mentioned, of the supposed "germinal membrane," and the consequent appearance of a "*lamina*," the two ends of which "*grow forth like liberated processes*," admit, I respectfully suggest, of a different explanation. That "*lamina*," the "*primitive portion of the embryo*," appears to me to correspond in its situation and manner of growth to the *germ*, which it has been my endeavour to show is the foundation of the mammiferous embryo. The membrane, however, (*am.* in Plates VI. and VII.) in Mammalia which becomes "drawn in" merely *invests* the embryo, and is *not continuous with it* (see par. 220.). Is it not really so with the "lamina" in question, in the amphibia above-mentioned, as well indeed as with the corresponding part in other animals?

252. Judging from my observations made on the mammiferous ovum, I am convinced that BAUMGÄRTNER§ has very accurately described a comparatively early appearance of the embryo of the Frog, as regards both form and substance.

253. It has been conceived‖ that in vertebrated animals the brain and spinal cord form on the *outer* side of the so-called "serous lamina of the germinal membrane," the foundation of the extremities being situated on the *tube* which that "membrane" has been supposed to form; but that in Invertebrata, the chain of ganglia arises on the *inner* or yelk side of that "lamina," and that the extremities on the other hand make their appearance on its *outer* side. I would submit, however, that the difficulty here has been in no small degree attributable to the prevailing opinion that the embryo arises in the substance and by the foldings of a membrane.

Recapitulation.

254. The difference perceptible between the mature and immature ovum consists in the condition of the yelk; the yelk of the mature ovum containing no oil-like globules (par. 120. 122. and *Note.* 124. *Note.*).

255. Both maceration and incipient absorption produce changes in the unimpreg-

† Flusskrebs, p. 86.

‡ The Professor here refers to the authority of PREVOST and DUMAS, of RUSCONI, and of BAER.

§ MÜLLER'S Archiv, 1835, Heft VI. The previous work of BAUMGÄRTNER, on the Frog, I regret to say I have not seen.

‖ RATHKE, Flusskrebs, pp. 77 to 91.

nated ovum, which in some respects resemble those referable to impregnation (par. 123. 124. 160.).

256. During the Rut, the number of Graafian vesicles appearing to become prepared for discharging their ova, exceeds the number of those which actually discharge them (par. 125.).

257. Ova of the Rabbit which are destined to be developed, are in most instances discharged from the ovary in the course of nine or ten hours *post coitum*; and they are all discharged about the same time (par. 128. 130.).

258. There is no condition of the ovum, uniform in all respects, which can be pointed out as the particular state in which it is discharged from the ovary; but its condition in several respects is very different from that of the mature ovum *ante coitum* (par. 140.).

259. Among the changes occurring in the ovum before it leaves the ovary, are the following, viz. the germinal spot, previously on the inner surface, passes to the centre of the germinal vesicle; the germinal vesicle, previously at the surface, passes to the centre of the yelk; and the membrane investing the yelk, previously extremely thin, suddenly thickens. Such changes render it highly probable that the ovary is the usual seat of impregnation. This opinion is not incompatible with the doctrine that contact between the seminal fluid and the ovum is essential to impregnation, since in the course of these researches it has been found that spermatozoa penetrate as far as to the surface of the ovary (par. 143 to 147.)†.

260. The retinacula and tunica granulosa are the parts acted upon by the *vis a tergo* which expels the ovum from the ovary. These parts are discharged with the ovum, render its escape gradual, perhaps facilitate its passage into the Fallopian tube, appear to be the bearers of fluid for the immediate imbibition of the ovum, and probably enter into the formation of the chorion (par. 148 to 151. 225.).

261. After the discharge of the ovum from the ovary, the ovisac is obtainable free from the vascular covering, which together with the ovisac had constituted the Graafian vesicle. It is the vascular covering of the ovisac which forms the *corpus luteum*. Many ova, both mature and immature, disappear at this time by absorption (par. 154. 156. 158.).

262. In some animals, minute ovisacs are found in the infundibulum; the discharge of which from the ovary appears referable to the rupture of large Graafian vesicles, in the parietes or neighbourhood of which, those ovisacs had been situated (par. 162 to 165.).

263. The diameter of the Rabbit's ovum when it leaves the ovary, does not generally exceed $\frac{1}{14}$ of a Paris line (= about $\frac{1}{135}$ of an English inch), and in some instances it is still smaller (par. 166.).

264. The ovum enters the uterus in a state very different from that in which it leaves the ovary. Hence the opinion of Baer, that "in their passage through the

† See the Notes to par. 145 and 278.

tube the ova of Mammalia undergo scarcely any metamorphosis at all," is erroneous (par. 181 to 183.). Among the changes usually taking place in the ovum during its passage through the Fallopian tube are the following; viz. 1. an outer membrane, the chorion, becomes visible; 2. the membrane originally investing the yelk, which had suddenly thickened, disappears by liquefaction; so that the yelk is now immediately surrounded by the thick, transparent membrane ("zona pellucida") of the ovarian ovum; 3. In the centre of the yelk, there arise several† very large and exceedingly transparent vesicles. These disappear and are succeeded by a smaller and more numerous set. Several sets thus successively come into view, the vesicles of each succeeding set being more numerous and smaller than the last, until a mulberry-like structure has been produced, which occupies the centre of the ovum. Each of the vesicles of which the surface of the mulberry-like structure is composed, contains a colourless and pellucid nucleus; and each nucleus presents a nucleolus (par. 170 to 180.).

265. In the uterus, a layer of vesicles of the same kind as those of the last and smallest set here mentioned, makes its appearance on the whole of the inner surface of the membrane which now invests the yelk. The mulberry-like structure then passes from the centre of the yelk to a certain part of that layer (the vesicles of the latter coalescing with those of the former, where the two sets are in contact, to form a membrane—the future amnion), and the interior of the mulberry-like structure is now seen to be occupied by a large vesicle containing a fluid and dark granules. In the centre of the fluid of this vesicle is a spherical body, composed of a substance having a finely granulous appearance, and containing a cavity filled with a colourless and pellucid fluid. This hollow spherical body seems to be the true germ‡. The vesicle containing it disappears, and in its place is seen an elliptical depression filled with a pellucid fluid. In the centre of this depression is the germ, still presenting the appearance of a hollow sphere (par. 184 to 186. 190. 189.)§.

266. The germ separates into a central and a peripheral portion§, both of which at first appearing granulous, are subsequently found to consist of vesicles. The central portion of the germ occupies the situation of the future brain, and soon presents a pointed process. This process becomes a hollow tube, exhibiting an enlargement at its caudal extremity, which indicates the situation of the future sinus rhomboidalis. Up to a certain period new layers come into view in the interior of the central portion of the germ, parts previously seen being pushed further out (pars. 193. 209. 197. 214. 212.).

267. From the region occupied by the germ there issues a hollow process, which by enlargement is made to line the inner surface of the ovum,—that is to say, the

† There arise at first two vesicles, then four or more, and so on. (See par. 174 and second Note, also par. 314 to 318.)

‡ See, however, the first part of the Note to par. 186.

§ See, however, the Notes to par. 186. 193. 197.

inner surface of the membrane entering into the formation of the amnion (which corresponds to the "serous lamina" of authors), and the process now lining it represents an incipient state of the subsequently "vascular lamina" of the umbilical vesicle —a lamina continuous with the structure corresponding to the "area vasculosa" of authors on the Bird (pars. 193. 201 to 204. 211. 216. 219. 220.).

268. There does not occur in the mammiferous ovum any such phenomenon as the splitting of a "germinal membrane" into the so-called "serous, vascular, and mucous laminæ" (par. 194 to 196.).

269. Nor is there any structure entitled to be denominated the "germinal membrane;" for it is not a previously existing membrane which originates the germ,—but it is the previously existing germ which, by means of a hollow process (par. 267.), originates a structure having the appearance of a membrane (par. 220.).

270. The structure entering into the formation of the amnion is no part of that which constitutes the embryo (pars. 199. 200.). The first appearance of the amnion is in the form of an epithelium (par. 184.). From the delineations of authors it appears to be a corresponding structure, which in Mollusca is the foundation of the shell, and in Crustacea and Arachnida that of the outer covering of the abdomen (pars. 243. 244.).

271. The most important of the foregoing facts respecting the development of the mammiferous ovum, however opposed they may be to received opinions, are in accordance with, and may even explain, many observations which have been made on the development of other animals, as recorded in the delineations of preceding observers (par. 243 to 253.).

272. The ovum may pass through at least one-and-twenty stages of development,—and contain, besides the embryo, four membranes, one of which has two laminæ,—before it has itself attained the diameter of half a line (par. 207.), a fifth membrane having disappeared by liquefaction within the ovum (par. 174.).

273. The size of the minute ovum in the Fallopian tube and uterus affords no criterion of the degree of its development; nor do any two parts of the minute ovum in their development necessarily keep pace with one another. The embryo sometimes attains a considerable degree of development in its form when exceedingly minute (pars. 218. 219. 167. 168.).

274. The proportion of ova met with in these researches in the uterus which seemed to be aborted, has amounted to about one in eight (par. 226.).

275. With slight pressure the ovum, originally globular, becomes elliptical. Its tendency to assume the latter form is referable chiefly to a property of the chorion, and seems to be in proportion to the size of this membrane (par. 230.).

276. The chorion is not—as was supposed in the "First Series" of these Researches —the thick transparent membrane ("zona pellucida") itself of the ovarian ovum, but a thin lamina which rises from the surface of that membrane, thickens, imbibes fluid, and is for a while separated from that membrane by the imbibed fluid. The fluid

then passes into the interior of the ovum, leaving the chorion again in close contact with the membrane from which it rose. That the lamina in question is really the chorion, has been shown by tracing it from its origin in the Fallopian tube up to the period when it becomes villous in the uterus (pars. 172.173.178.180.182.221 to 225½.).

Postscript.

277. It was not until after the foregoing memoir had been presented to the Royal Society, that a recent work by Professor Rudolph Wagner, on the Physiology of Generation and Development†, came into my hands. That volume contains an account of some researches by Bischoff on the ovum of the Dog in the Fallopian tube and uterus, which (though the plates intended to illustrate them have not yet appeared) it may be proper to notice here.

278. It is easy to understand that the ova of the Dog and Rabbit should, even at a very early period, be distinguishable by peculiarities in their development; but it is difficult to account for differences so remarkable as those which present themselves on comparing the statements of Bischoff with my own. There are only two observations, indeed, in which we seem to be agreed; viz. that the Spermatozoa penetrate as far as to the ovary‡, and that ova are often found lying near together in the Fallopian tube. In other respects there appears to be little or no agreement between the observations we have respectively recorded. Several of these, however, relate to points of cardinal importance. Thus Bischoff maintains that the ovum receives no new external covering, but that the "zona pellucida" of the ovarian ovum is identical with the chorion of the uterus. This, as already stated, was formerly my own opinion; and so nearly are the disappearance of one membrane and the coming into view of another membrane simultaneous, that it was not until near the close of these Researches that I was undeceived (par. 221.). Bischoff states that during the passage of the ovum of the Dog through the tube, the yelk undergoes changes in its form, becoming angular; and he mentions certain granulous rings of what he supposes the second or inner membrane; also that in some ova *from the uterus* he found the yelk uniform (in its consistence) and opake. I refer to my own figures for an explanation of those apparent rings; and am compelled to add, that in the ovum of the Rabbit I have not met with any solid substance uniform in its consistence, for a considerable period *before the exit of the ovum from the Fallopian tube.* Can it have been that the

† Lehrbuch der Physiologie, Erste Abtheilung, Physiologie der Zeugung und Entwickelung. Leipzig, 1839. This work contains within the small compass of 140 pages, a luminous account of the present doctrines on generation and development, together with a number of new facts observed by the author.

‡ A Note has been added in a preceding page (par. 145.), acknowledging that Bischoff preceded me in this discovery. Towards the end of June 1838 he observed Spermatozoa on an ovary of the *Dog.* On the 5th of the following September I found those animalcules on an ovary of the *Rabbit,* and the next day (Sept. 6) observed a single Spermatozoon on the ovary of another Rabbit. Early in the following December R. Wagner found Spermatozoa in the Dog between the fimbriæ, close to the ovary.

successive groups of vesicles (Plate VI. figs. 105½ to 110.) which occupy the centre of the ovum (and are finally (fig. 113.) found to contain the germ in their interior) were described by BISCHOFF as an "angular" yelk? That observer recognises a "germinal membrane" in the ovum of the Dog. According to my observations the embryo of the Rabbit does not arise in the substance of a membrane†.

279. In addition to the foregoing statements of BISCHOFF, it may not be improper to refer to existing views rather more fully than I have hitherto done; from which it will perhaps appear that the difference between many of those views and the opinions I have been compelled to form, is mainly attributable to the absence of a suite of early stages.

280. R. WAGNER, in the latest work that has appeared on the subject‡, remarks as follows. "In mature ova, impregnated or susceptible of impregnation, the germinal vesicle disappears. How this takes place, whether in consequence of a sudden bursting, or through rapid dissolution and liquefaction, flattening down, diminution of its contents, &c., does not admit of being with certainty determined; so much is certain, that the germinal vesicle has always disappeared as soon as the ovum has left the ovary. On the immediate changes consequent upon the disappearance of the germinal vesicle we have no more than mere hypotheses, for observation has hitherto given no explanation of them." The same eminent author subsequently remarks, "Of all occurrences in the history of development, the reception of the ovum into the tubes, and its progress until it reaches the uterus, is the most veiled in obscurity. In Man no one has yet succeeded in observing ovula in the tubes: and it belongs to the most difficult and delicate of anatomical examinations to discover objects so minute even in Mammals, in which the time of impregnation may be so exactly known. In Rabbits the ovula pass into the uterus from three to five days after impregnation, in Dogs from ten to twelve days. In these animals—whose earliest period of development is the best known—several ova are separated and pass in succession—rarely together—into the uterus; and it would seem that the Graafian vesicles also often do not all burst at the same time, but that single ones may burst several days before the rest. The ovula undergo but little change during their passage through the tubes; they take with them from the Graafian vesicle a part of the granulous stratum, which as an irregular, lacerated, disc-like structure, remains adherent to them, but is soon stripped off§." "As soon as the ovula have passed out of the oviduct into the uterus, they undergo the first remarkable changes, and grow rapidly. The following applies chiefly to the Dog and Rabbit, whose ova have been the most frequently examined.

† Since the above was written I have seen the plates of R. WAGNER's work, referred to in par. 277 (Icones Physiologicæ. Fasciculus primus, 1839). They are truly admirable. In reference, however, to the Figures from Professor BISCHOFF (tab. VI. fig. III. to VIII.), I am compelled to state my belief, that while they serve to show this very talented observer to be in advance of others in his acquaintance with the mammiferous ovum, they also confirm an opinion I had previously formed—that he did not obtain a suite of early stages.

‡ Lehrbuch der Physiologie, 1839, pp. 57, 58.

§ p. 94.

The ova, which in the ovary measured only $\frac{1}{18}$ to $\frac{1}{12}$ of a line, have reached the size of $\frac{1}{3}$ to $\frac{2}{3}$ of a line. It is distinctly seen that the chorion distends and becomes thinner; the yelk-ball swells, but becomes more fluid; as the dark granules disappear larger drops of oil come into view; at the same time the superficial granulous layer of the yelk acquires a membrane-like consistence, and the granules present little accumulations, which are insulated, and soon form, at a certain place, an opake circular spot, which in ova measuring a line is perceptible as a minute point with the naked eye. This spot consists of a stronger aggregation of granules, which rises somewhat scutiform—being thicker than the remaining membrane—and soon becomes rather more pellucid in the centre, while the granules group themselves wall- or ring-like at the circumference. The granules of this disc appear to be distinct cells [vesicles], having in the centre a minute opake nucleus. The double membrane of these minute ova is seen very distinctly when the ova have been but a few seconds in water; the outer perfectly transparent membrane—which has no distinct structure—separates very quickly from the inner, which invests the yelk and bears the granulous spot. The outer membrane is the former chorion ['zona pellucida'], the inner is the germinal membrane, blastoderma, which as a membrane has already grown around the entire yelk, and perhaps at an earlier period—as a continuous granulous layer—invested the same, while in the Bird as a disc-like object it occupies only a minute space on the yelk. Probably the space between the two membranes is filled with a thin layer of albumen, which the ovulum has acquired in the oviduct and uterus, and which swells by imbibition in water, producing a greater separation of the two membranes. The granulous spot is the place from which the formation of the embryo proceeds, and hence has by some been called the embryonal spot (tache embryonnaire of Coste). Whether the outer membrane continues to be the most external and becomes the villous chorion, or whether yet a delicate membrane, as exochorion, forms around it, which some maintain, is doubtful; but the former is the more probable. The ova still lie loose in the uterus, and have passed from the round to the oval form †."

Rotatory Motions of a Mulberry-like Object in Vesicles under the Mucous Membrane of the Uterus.

281. In the course of my researches on the mammiferous ovum I have seen in the uterus of the Rabbit minute pellucid vesicles under the mucous membrane of that organ. These vesicles are frequent in that part of the uterus (under its mucous membrane) which joins the Fallopian tube. By enlargement they resemble ova; and the observer is sometimes not undeceived until he attempts to lift them from their situation. The uterus has generally been more or less highly vascular when the subject of my examination. Whether the vesicles in question present themselves in other states of this organ I do not know; but on the inner surface of what seemed one of

† pp. 97, 98.

those vesicles was seen a beautiful display of newly-formed vessels, in which the red particles of the blood were scarcely at rest, or at least were set in motion by the slightest descent of the compressorium. I have been ready to imagine that the origin of these vesicles in the uterus, and the phenomenon about to be recorded, may be connected with the formation of the blood-vessels and blood. The form of the vesicles in question is not regular; and I have observed an obscure appearance, possibly indicating a communication between their cavities and a more internal part.

282. Being engaged in laying open for examination the oviduct of a Rabbit, I found a little mass adherent to the instrument, which on being viewed in the microscope was found to be a detached portion of its inner membrane. Imbedded in this little mass was a vesicle (Plate IX. fig. 151.) of an ellipsoidal form, $\frac{1}{4}'''$ in length, consisting of a tolerably thick membrane, having on its inner surface a layer of elliptic granules (vesicles?), and containing a pellucid fluid. This being apparently one of the vesicles in question, would not perhaps have been examined farther, but for a remarkable phenomenon observed in its interior.

283. In the centre of the fluid of the vesicle there was an object (see the figure) resembling the mulberry-like structure, which I have described in the mammiferous ovum (Plate VI. figs. 109 to 112.), actually *revolving on its own axis.* The revolutions were in the vertical plane, a direction which was not observed to change. In point of time they were not quite regular, being sometimes rapid, while at other times the object seemed nearly, though not quite at rest. Twice the revolving body was observed suddenly to shift its situation in the fluid, make a short circuit, and then almost immediately return to the centre of the vesicle. It had a diameter of $\frac{1}{350}'''$. Granules (vesicles?) were occasionally seen to start from their situation in the layer lining the membrane of the vesicle, and move towards the centre of the fluid; but they were not observed to attach themselves to the revolving body.

284. The object was watched revolving for half an hour, at the end of which time its revolutions terminated rather suddenly. The little mass then for a few seconds seemed to be at rest. It next assumed a tremulous motion, which—interrupted for a few seconds by a renewal of the revolutions—continued for about fifteen minutes, making three quarters of an hour in all, during which the object was observed to be in motion. And it is deserving of remark, that the Rabbit had been killed an hour and half before the examination was begun. Having ceased to move, the little mass was broken up by the compressor, when some of its parts, still hanging together, presented a renewal of the tremulous motion just mentioned. During these observations ciliary motions were very vivid on the mucous membrane investing the vesicle in question. They had become languid when the revolutions ceased. No cilia were observed on the revolving object itself; but cilia may have been present, and from their minuteness invisible†.

† On the subject of cilia as a cause of rotatory motion, I refer to Professor SHARPEY's excellent paper in Dr. TODD's "Cyclopædia of Anatomy and Physiology," vol. i. p. 606.

285. I cannot better describe the appearance of the object now referred to as revolving on its own axis, than by stating that it would not have been easy to distinguish it from the mulberry-like structure (Plate VI. figs. 109 to 112.) occupying in certain stages the centre of the mammiferous ovum, and containing the structure which I consider to be the primordial germ. The revolving-object in the vesicle (Plate IX. fig. 151.) was however smaller. The vesicles (fig. 152.) composing the surface of the mulberry-like structure in these vesicles vary in their size, many of them measuring $\frac{1}{100}'''$. Among them I have repeatedly observed several globules, or rather vesicles, which appeared to have occupied the centre of the mass. They were larger than those at the surface, granulous, yellowish-brown in colour, and contained themselves a globule. In some instances I have observed the whole mulberry to be tinged yellowish-brown, the colour being deepest in the centre of its vesicles. The vesicles, it will be observed (fig. 152.), contain objects (nuclei?) in their interior.

286. The phenomenon of *rotation* of the central mass in these vesicles I have seen only once, but it has not been particularly sought for. Frequently, however, has the existence of such a mass been observed with the same mulberry-like form. And in repeated instances the vesicles of the mass, more or less separated, have exhibited the tremulous motion above mentioned. In one instance the motion was comparable to that observed in separate globules when in the neighbourhood of cilia in motion.

287. It has been remarked by Professor BURDACH†, that "the mammiferous ovum, not only in its form, but also in its vital relations, resembles a hydatid." The resemblance, however, was probably not conjectured to be so very close as from the above facts it appears to be. (Compare Plate IX. fig. 151. with several of the figures in Plate VI.) It remains to be discovered whether the mulberry-like structure with its germ in the ovum of Mammalia, also performs rotatory motions. The thought that it may do so has naturally suggested itself, from the striking resemblance in form, composition, and locality‡ of that structure in the mammiferous ovum and the uterine vesicles in question.

288. It is known that the *embryos* of a number of Mollusca, as well as the *germinal granules* of some Polypes, &c., perform rotatory motions. We are indebted to Professor GRANT for some very interesting facts on this subject. Several observers have noticed this phenomenon in the *ova*, or *yelk-ball*, of certain animals. An instance of its occurrence in the latter appears to have been observed by LEEUWENHOEK in 1695, but the subject claimed little attention until revived by CARUS and E. H. WEBER. CARUS§ has investigated the subject in Mollusca. With reference chiefly to the ob-

† *L. c.*, vol. ii. p. 820.

‡ It is not unusual to meet with vesicles in which the object in question appears to have left the centre of the cavity, and approached the membrane on one side (par. 185.).

§ Von den äussern Lebensbedingungen der weiss- und kaltblütigen Thiere, 1823; and Neue Untersuchungen über die Entwickelungsgeschichte unserer Flussmuschel, 1832.

servations of the last-named author, BURDACH† states the following regarding the ova of *Limnæus stagnalis*. "With the incipient formation and development of an embryo, the yelk-ball performs in the vertical plane [par. 283.] rotatory motions around its axis, the cause of which has not been satisfactorily explained. The yelk granules *swell*, and become large and *vesicular*. After some days the revolutions become weaker." Is it not possible, that the so-called "yelk" in this instance, the granules of which became "*vesicular*," really corresponded to the mulberry-like structure I have met with in the ovum of Mammalia and in the vesicles just mentioned? CARUS‡ has mentioned rotatory motions as occurring in the ova of *Unio tumida*. These were horizontal, and accompanied by a change in the form of the yelk. The same observer saw in *Anodonta intermedia* corresponding motions, which were subject to temporary cessation, and the direction of which was irregular.

289. It is an interesting fact, that in two out of the three genera above mentioned —as affording examples of revolving ova—there has been observed a structure that appears to be essentially the same as that which I have met with in the ovum and the uterine vesicles in question of Mammalia, producing the appearance of a mulberry.

Correspondence in the Elementary Structure of Animals and Plants.

290. Few microscopic investigations have led to discoveries so interesting and important as those of SCHWANN§ on the correspondence in the structure and growth of animals and plants; and certainly no stronger proof can be required of the importance of the history of development to physiology. That author, basing his researches in the animal upon the discoveries of SCHLEIDEN‖ in the vegetable kingdom, has demonstrated that in development the same phenomena are exhibited in both. He has shown not only that animal tissues in general, like those of plants, are reducible to modifications of vesicles, or as he calls them "cells,"—but that the mode of origin of the vesicles or "cells" is essentially the same in animals as SCHLEIDEN had discovered it to be in plants. The membrane of each vesicle or "cell" is formed at the surface of a previously existing nucleus, which is a minute, spherical, or elliptical, and often flattened body, having a granulous appearance, and found by SCHLEIDEN in many instances to contain a nucleolus¶. The membrane of the vesicle was found by SCHLEIDEN to rise from the nucleus, and in the early progress of distention to present an appearance which he compares to that of a watch-glass on a watch. The analogy now mentioned extends to organized as well as unorganized animal tissues; and even the blood-vessels are formed of vesicles or "cells." Farther, elementary parts, which in a physiological point of view are entirely different, have been shown by SCHWANN to

† *L. c.*, vol. ii. p. 224. ‡ Neue Untersuchungen, &c. § Mikroskopische Untersuchungen, &c.

‖ "Beiträge zur Phytogenesis," in MÜLLER's Archiv, 1838. Heft II.

¶ The nucleus had been known to other botanists, its importance having been first conceived by our very distinguished countryman ROBERT BROWN; but its property of originating the "cell" was the discovery of SCHLEIDEN, who from this property proposes to denominate it the "*Cytoblast*."

follow the same laws in their development. Thus whether a muscular fibre or a nervous tube is destined to be formed, the foundation of both consists of vesicles or "cells," which have arisen in the manner above described; and it is through the modifications which the vesicles undergo, that a muscular fibre on the one hand, or a nervous tube on the other, is produced. "In short, there is for all the elementary parts of organisms a common principle of development."

291. It will be interesting to refer to a few of the facts recorded in the foregoing and the previous memoir, in connexion with the analogy now mentioned; and if those facts should be found in any way to exemplify it, they will not be the less admissible from my having observed them in the course of researches in which this analogy formed no part of the object I was in pursuit of.

292. Both the nucleus and nucleolus were figured in my "First Series†," in the peculiar granules, or rather vesicles of the ovisac, though I was ignorant of their importance. It will be seen indeed that those peculiar granules (vesicles) form a part of more than fifty figures in that paper, and that the nucleus is represented in almost every instance where the size admitted of it. This is mentioned merely to show that those objects (the nucleus and nucleolus) were not overlooked, for to SCHLEIDEN belongs the merit of first pointing out the nature of those objects in plants, and to SCHWANN that of recognising corresponding structures in animals. That memoir contained also the drawing of a spot‡ on the inner surface of the membrane of the yelk in the ovum of the Frog. Of that spot I did not attempt to offer any explanation, simply stating its appearance as "a spot which I always find on the internal surface of the membrana vitelli of the Frog in ovisacs of about this size [$\frac{1}{3}'''$]. This spot does not appear to have been hitherto described. It is generally elliptic, rarely round, has a well-defined contour, and is perhaps slightly lenticular in form. In this instance it measured $\frac{1}{32}'''$ in length, and is often of about the same size. It appears to be composed of granules§." The spot in question is obviously the nucleus of the membrane or vesicle on the inner surface of which it occurs‖.

293. The vesicles which constitute the outer portion of the mulberry-like structure (Plate VI. fig. 110., Plate VIII. fig. 130.) present each a nucleus¶ and nucleolus.

† *L. c.*, Plate VIII. fig. 73.

‡ *L. c.*, Plate VI. fig. 28. d^1, and in the present paper, Plate V. fig. $84\frac{1}{2}$. *x*. § *L. c.*, par. 40.

‖ The existence of this spot will probably be found of some importance in determining the order of formation of the several parts of which the ovum is composed. And it is proper to state, that SCHLEIDEN's discovery in plants of the origin of vesicles ("cells") on a nucleus, and the extension of this discovery to animals by SCHWANN, must necessarily modify some of the conclusions in my "First Series" as to the order of formation here referred to; but in the present series this has not been the subject of investigation. I would remark, however, that if the spot on the inner surface of the membrana vitelli in the ovum of the Frog is present in the corresponding membrane of other ova, the formation of this membrane is doubtless earlier than that of the germinal vesicle itself (par. 242.). I have observed the stroma in the neighbourhood of an ovisac to appear as if composed of vesicles with nuclei.

¶ It is not probable, however, that the nucleus here referred to is of the same kind as that called the "Cytoblast" by SCHLEIDEN (see par. 317. and its last Note.).

294. The vesicles composing the layer (*am.*) on the inner surface of the membrane *f* (Plate VI. figs. 111 to 117., Plate VIII. fig. 129) have each their nucleus‡ and nucleolus. Hence the amnion—formed as it is out of these vesicles—may be added to the structures already found to be referable to a "cell"-formation.

295. The lamina in which I suppose the blood and blood-vessels to form, presented in its mode of origin a series of changes which do not seem to have been before observed in any animal, and it will be seen that they are most intimately connected with the present subject. (See par. 196. 197. 201 to 204. 211.).

296. The yelk-globules are true vesicles, containing other vesicles (Plate V. fig. 87.). The villi of the chorion are vesicles in which I observed objects having the appearance of vesicles (Plate VIII. fig. 141.). The whole embryo indeed is composed of vesicles (Plate VIII. figs. 121 A. 121 B. 122. bb^1. and bb^2.); and *even the primordial germ itself* (Plate VI. fig. 113. *bb.*) seems to have been the nucleus of the vesicle in the centre of which it lies†.

297. I have now to mention a fact or two regarding the nature and properties of nuclei. SCHLEIDEN supposes the nucleolus to exist before the nucleus, and SCHWANN believes that he has observed the formation of the nucleus to take place around the nucleolus. Hence the last-mentioned observer considers that it may be said, "the formation of the cell [vesicle] is only a repetition around the nucleus, of the same process through which the nucleus was formed around the nucleolus;" the difference being only in degree. In connexion with this view SCHWANN refers to the fact, that nuclei often become hollow vesicles. On the period of origin of the nucleolus I have no observations, except that its existence was not appreciable in any of the nuclei represented in Plate VII. figs. 120 and 121‡., and not in all of those in Plate VIII. fig. 150‡. Several observations, however, enable me to state that objects occupying the situation of nuclei are sometimes hollow vesicles. Such for instance was their condition in the amnion (Plate VIII. figs. 129. 130‡.) and in the lamina subsequently vascular (fig. 150‡.). I have also observed that with incipient decomposition of the peculiar granules (vesicles) of the ovisac, their nuclei appear like vesicles, filled with a colourless and pellucid fluid (Plate V. fig. 102. *g.*). Whether this results from distention of the nucleolus (frequently seen to be hollow), or from liquefaction of the contents of the nucleus including the nucleolus, I do not know.

299. The following observation (before noticed) may serve to extend our knowledge as to the properties of a nucleus. If Plate V. fig. 89. *b.* be referred to, it will be seen that the germinal spot (as such) has disappeared, and that in its stead are several vesicles with intermediate granules§. From those vesicles the germinal vesicle (*c.*) did not appear to differ except in its greater size. This was the effect of incipient decomposition. Here then the germinal spot (possibly, as supposed by SCHWANN, a

† See the first part of the Note to par. 186. ‡ See the Note to par. 293.

§ In the ovum Plate V. fig. 86. the same phenomenon was observed, though with less distinctness.

nucleus in reference to the germinal vesicle) was seen to have resolved itself into vesicles; a fact, which seems deserving of notice, as being the result of decomposition.

300. The primordial germ, as already stated, seems to be a nucleus. And here we find the most important of all nuclei resolving itself entirely into vesicles,—the first of these vesicles containing that which I have denominated the peripheral portion of the germ (Plate VIII. fig. 148. bb^2.). (See the *primitive* changes in the germ par. 209. 212 to 215. 312. and Plate VII. figs. 121 A. 121 B. 122.)†.

301. The vesicles exhibited in Plate VIII. fig. 149. constituted part of the incipient embryo in an ovum of 111½ hours and measuring $\frac{1}{3}'''$. They were drawn after removal from their situation, and after the ovum had lain forty-eight hours in kreosote water. It will be seen that those vesicles contained two or even three minuter vesicles, inclosed the one within the other. The arrangement was not concentric, all the vesicles being in contact at a certain point, while on the other side there were intervening spaces. This was observed to be the case with the vesicles into which the germinal spot, above referred to, had resolved itself (Plate V. fig. 89. *b*.) from incipient decomposition.

302. In these researches no objects have so frequently been met with as those which I have called "dark globules." They present themselves with the earliest appearance of the ovum (Plate V. figs. 81 to 83.), and in many stages of its development. Wherever a part is beginning to be formed, or the formation is vigorously proceeding, there are seen dark globules. The yelk, the peculiar granules (vesicles) of the ovisac, and the villi of the chorion afford examples. They are present in very large quantity, among the vesicles of which the incipient embryo is composed (Plate VIII. fig. 149.); and here they appear to be no other than the foundations of new vesicles. (Compare the inner with the outer part of bb^1 in Plate VII. fig. 121 A.) I am disposed to think that this is the case in many other instances. For example, the vesicles destined to form the villi of the chorion arise in this manner (par. 223.); and the dark globules of the yelk we have seen to be true vesicles containing other vesicles (par. 121. and Plate V. fig. 87.).

303. The space between the membrane of an outer and the membrane of an inner vesicle (or nucleus) seems in many instances to be the place of origin of dark globules, or incipient vesicles‡. During the *primitive* changes in the germ (par. 312.)

† The resemblance in position and appearance between the germ (Plate VI. fig. 113. *bb*.) and the germinal spot after impregnation (Plate V. figs. 93 and 96 *b*.) is very remarkable. So great is this resemblance that at first I supposed and recorded it to be the germinal spot and vesicle again coming into view. And it has been only in consequence of my inability to discover these objects in intermediate stages (such as those represented in Plate VI. fig. 105½ to 108.) that I have been induced to give up the opinion that the germinal spot is identical with that which I have called the germ; and to maintain (as I am compelled to do) that the germ is a new formation, not originating until after the ovum has been fecundated. The resemblance between the subsequent appearance of the germ, as composed of vesicles (Plate VII. figs. 121 A. to 122.), and the condition of the germinal spot when undergoing decomposition (Plate V. fig. 89. *b*.), is not less remarkable. (See, however, the first part of the Note to par. 186, and the Notes to par. 193 and 197.)

‡ In plants, according to SCHLEIDEN, the origin of vesicles within already existing vesicles is nearly or quite

an example of this occurs (Plate VII. figs. 121 A. to 123. bb^1.). Each of the concentric layers of which the germ consists, is so distinctly circumscribed as to appear delicately membranous at its surface (par. 212.); or in other words, each concentric layer appears to be contained within a vesicle. Now here, as just stated, the intervening spaces are occupied by dark globules, subsequently forming vesicles.

304. More particularly considered, the situation, and perhaps the place of origin of the dark globules in question, is in some instances *on the outer surface of the inner vesicle or nucleus*; of which Plate VIII. fig. 150. affords a remarkable example, in the lamina subsequently vascular†. The dark globules in the network Plate VIII. fig. 132. in every instance surround the nucleus†. The yelk-globules (vesicles) seem to arise on the outer surface of the germinal vesicle‡†. In other instances the foundations of new vesicles arise as dark globules on the external surface of an *outer* vesicle. This is the case with the vesicles forming the villi of the chorion (par. 223.); and perhaps the "isolated spots" occurring in the Graafian vesicle may be mentioned as another example§.

305. On the liquefaction of the membrane of a vesicle dark globules are sometimes liberated. This takes place, for instance, when the membranous portion of the network (composed of vesicles, par. 201.) Plate VIII. fig. 132. disappears. (See Plate VII. fig. 120. Whether the dark globules which the latter figure shows to have been set free, are the foundations of new vesicles, I do not know; but in an ovum of about the same size the corresponding part presented vesicles in such quantity as to be pressed together into polyhedral figures, Plate VIII. fig. 150. From some observations on the vesicles of which the incipient embryo is composed, I am disposed to think the dark globules exhibited in Plate VIII. fig. 149. (or a part of them) may have been liberated in the same manner.

306. In Plate VIII. fig. 143. is an ovum of twenty-three hours from the Fallopian tube. It was found with five others, and they were all lying very near together. These ova had penetrated about $\frac{1}{4}$ to $\frac{1}{3}$ an inch into that part of the tube where its calibre suddenly diminishes; a part which when rolled between the fingers is found to resemble the vas deferens. In this ovum (fig. 143.) the chorion had not separated

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universal. In the formation of animal tissues, on the other hand, SCHWANN found this to be rarely the case. The observations, however, now referred to, of the origin of vesicles in vesicles, relate to a period anterior to the formation of even the elementary parts of tissues (nervous tubes, muscular fibres, &c.), and therefore are not necessarily opposed to those of SCHWANN.

† See the Note to par. 293.

‡ See my "First Series," *l. c.*, Plate V. figs. 14 and 16. It is interesting to find, as already stated, not only that the *formation*, but also that the *liquefaction* of the yelk-globules (vesicles) begins around the germinal vesicle (Plate V. figs. 99 and 100.).

§ These "isolated spots" were described in my "First Series" (par. 59. Plate VIII. fig. 66.) as consisting "of one of the peculiar granules [vesicles] of the Graafian vesicle, having a peripheral accumulation consisting of oil-like globules."

from the membrane *f*, but it was visible as a dark line surrounding the latter. (See also Plate VI. fig. 104. *a*.) The membrane *f* contained two objects measuring respectively $\frac{1}{75}'''$ and $\frac{1}{115}'''$ in length†. Those objects had the appearance of two yelk-balls, and I am by no means sure that this was not the case. It seems possible, however, that they arose from a division of the previous yelk-ball into two portions. If so, this ovum was in a stage between that represented in Plate VI. figs. 105 and 106‡. The resemblance it bears to the ovum of Batrachian Reptiles after the first division of the yelk has taken place is remarkable§, and favours the latter supposition. Having met with but a single ovum in this state, however, I must leave this question for future observation to decide. In each of the two objects present in the ovum now referred to (Plate VIII. fig. 143.) there was observed a brilliant point.

307. The stages of the mammiferous ovum, exhibited in Plate VIII. figs. 106 to 108. presenting as they do successive sets of vesicles, each set consisting of smaller and more numerous vesicles than the last, suggest the idea that in the interior of each vesicle there arise two or more infant vesicles, the parent vesicle in each instance disappearing by liquefaction. Those later stages also bring to mind the divisions and subdivisions first observed by Prevost and Dumas in the ovum of Batrachian Reptiles, and since found by Rusconi to occur in some osseous Fishes; suggesting also that these divisions and subdivisions may be referable to the formation of vesicles‖. Rusconi observed in the ovum of the Frog that some of the masses

† The *yelk-ball* in the other ova found at the same time had a diameter in one instance of $\frac{1}{70}'''$, and in another of $\frac{1}{77}'''$.

‡ It will be observed that the ovum Plate VIII. fig. 143. is exhibited on a larger scale than the ova in Plate VI. fig. 105 and 106.

§ Compare Plate VIII. fig. 143. with figures by Rusconi of the ovum of the Salamander and the Frog (Müller's Archiv, 1836. Heft II. Tab. VIII.).

‖ Schwann, without knowing of the formation of the vesicles which I have described in the centre of the mammiferous ovum, conjectured that possibly the divisions in the ovum of the Frog, &c. might be reducible to a formation of vesicles; "two vesicles first developing themselves within the yelk, in each of the same two new vesicles, and so on." (*l. c.*, pp. 61. 62.). Bischoff after observing the yelk to have, as he supposed, an "angular" appearance in the ovum of the Dog, proceeds, "I have sometimes seen forms so remarkable, that the thought occurred to me, whether the yelk of the mammiferous ovum also undergoes changes in form similar to those in the ova of Fishes and Batrachians. But unfortunately these forms of the yelk are very soon lost, as soon as the ovum is placed in water or saliva, probably through imbibition of this fluid. Hence I have not been able to note some of them." (*l. c.*, p. 96.) It appears to me, that what Bischoff here terms "remarkable forms of the yelk" must have corresponded to my mulberry-like structure in its different stages.—That observer concludes the account of his researches with the following remarks. "Putting together my more recent with the earlier observations, I think the process of the formation of cells is the following: the yelk-granules first group themselves in smaller globular masses [nuclei], which then become surrounded by a cell. With the growth of the cell the granules separate from one another, group themselves in concentric rings, and now the nuclei become new cells, until at last each yelk-granule is surrounded by a cell, and the germinal membrane is so formed as in figs. VII. and VIII., where each cell contains a simple nucleus. In figs. IV. and V. the cells are still few, and hence there are many granules in each; in fig. VI. there are already more vesicles and the granules are fewer; in figs. VII. and VIII. the cells are still more numerous and each contains only one

(vesicles?) resulting from the divisions and subdivisions, presented cavities in their interior. VON BAER† and RUSCONI‡ have both figured a flattened "cavity" in the ovum of the Frog on that side where the divisions and subdivisions (i. e. the formation of vesicles?) had most rapidly proceeded. Does this "cavity" correspond to my vesicle which contains the germ§?

Anomalous Ova.

308. The object represented in Plate VIII. fig. 144. was found with four ova in the uterus about $\frac{3}{4}$ inch from the Fallopian tube. The period was $111\frac{1}{2}$ hours. The ova measured about $\frac{1}{3}'''$; the object in question $\frac{1}{11}'''$. The latter consisted of the following parts; viz. an outer membrane (*f*), resembling the thick transparent membrane ("zona pellucida") of the ovarian ovum; an inner pear-shaped membrane (*e*), $\frac{1}{40}'''$ in length, having considerable thickness; and in the interior of this second membrane, two vesicles, one of which measured $\frac{1}{30}'''$, the other $\frac{1}{30}'''$. The membranes of these two vesicles also had considerable thickness. All the membranes were transparent, and contained a colourless transparent fluid. The two smallest vesicles presented a mass in their centres having a granulous appearance. I am disposed to think this object was an ovum, but it is not easy to determine the nature of its parts‖. On another occasion I found in the uterus an object of $\frac{1}{4}'''$ resembling the above, but the second membrane (*e*) was not present.

The origin of Tissues subordinate to a division into forms.

312. It will be remembered that the germ when first seen has the appearance of a granulous thick-walled hollow sphere, containing a brightly pellucid fluid (Plate VI. fig. 113. *bb.*), and that this object having separated into two portions (Plate VIII. fig. 148. bb^1 and bb^2.), the central portion undergoes the following changes¶. It presents a pointed process (Plate VII. fig. 118. bb^1.), and resolves itself into vesicles,

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nucleus. If we would extend this process still farther, the changes in form of the yelk are indeed so determined, that in the first place all the yelk-granules are inclosed in two, then in four, then in eight, &c. cells, until each yelk-granule has its cell and *therewith the germinal membrane is formed until the arising of the embryo.* The cells are besides of different sizes; in figs. IV. and V. most of them measured 0,0014 to 0,0018 Par. inch, but some only 0,0008 Par. inch." (*l. c.*, pp. 100, 101.). (See par. 314 to 317.)

† MÜLLER's Archiv, 1834, Heft VI. ‡ *Ib.* 1836, Heft II.

§ Should the analogy in question really exist, it will prove that RUSCONI was correct when he stated, in opposition to the opinion of BAER, "that the furrows in the ovum of the Frog are the *effect* of impregnation, and not the means by which impregnation is facilitated." (MÜLLER's Archiv, 1836, Heft II. p. 208.)—R. WAGNER adopts this opinion of RUSCONI (Lehrbuch, &c.).

‖ Farther observations have satisfied me that this was an ovum aborted in a stage between the conditions represented in Plate VI. figs. 105 and $105\frac{1}{2}$ (see par. 317. *Note.*). The other object above mentioned as measuring $\frac{1}{8}'''$, appears to have been an ovum aborted in the state represented in Plate VI. fig. $105\frac{1}{2}$. In neither of these ova had the chorion arisen.

¶ See, however, the Notes to par. 193 and 197.

which are disposed in layers (figs. 121 A. to 122 *bb*[1].). Layer after layer comes into view in the interior (each layer appearing as if invested by a delicate capsule), while those previously occupying that situation are pushed farther out. These changes may be called *primitive*†, for at a certain period no more layers make their appearance, and the cavity inclosed by the most central layer becomes enlarged. It is very interesting to observe, that before those *primitive* changes have reached their limit, a structure is produced (by the layers of vesicles in question) having the *form* of the central portion of the nervous system, including even the sinus rhomboidalis of the spinal cord‡. It is also interesting to find that the foundation of the vascular system is a part of the primordial germ (par. 216.). The nature of the alterations which the germ undergoes immediately after the termination of the primitive changes now referred to, I do not know, not having carried my investigations beyond that period. It is probable that they consist chiefly in the formation of new vesicles. The object represented in figs. 125 and 126.—met with incidentally—was in a much more advanced state as to *form*, and exhibited an incipient division into further forms (par. 218.); yet it presented no trace of separation into tissues. *The origin of tissues, then, is subordinate to a division into forms.* This may serve to elucidate the fact, that parts in different animals, having a general resemblance in *form*, are sometimes the seat of very different *functions*. And if the primordial germs of organized beings in general resemble one another in appearance, as much as, from my observations, it appears that they do in some instances very remote from one another, it is not surprising that there exist resemblances in the subsequent *forms* of beings more nearly allied. I refer, for example, to a curious resemblance between the mammiferous germ with its vesicle—as exhibited in Plate VI. fig. 113.—and the "cytoblast" and spore of a cryptogamous plant (*Rhizina lævigata*),—as figured by SCHLEIDEN in his paper on vegetable structure§. This observation will perhaps be considered as not undeserving of notice in connexion with the subject of analogies in the fundamental structure of organized beings. We find also, that there is a period in the formation of the Mammal —and therefore, it may be presumed, of Man himself—when the immediate foundation of the new being is contained within a simple "cell," vesicle, or sac.

Method of obtaining the minutest Ova in the Uterus and Fallopian Tube; and a mode of preserving them while under examination.

313. The almost entire absence heretofore of observations on the smallest ova in the oviduct of the Mammalia, may be attributed to the difficulty experienced by ob-

† The separation of the germ into a central and a peripheral portion being the first of these *primitive* changes.

‡ I apprehend it would be an error to suppose that the fluid contained within a tube is the first appearance of the central portion of the nervous system. Its original foundation seems to be present from the first; and its form, as above stated, is seen before that of any other part. The object represented in Plate VII. figs. 125 and 126.—and more particularly its inner part—I am disposed to think consisted chiefly of the foundation of the central portion of the nervous system.

§ *L. c.*, Tab. III. fig. 11.

servers in obtaining objects so minute, and to their inability to apply to those delicate objects—when found—an equally delicate manipulation. My own efforts were for a long while nearly fruitless from the same causes (par. 166.). But experience having at length enabled me to surmount in some degree those difficulties, I will describe the means by which this may be accomplished. Before commencing the examination I provide several discs of glass, of about the diameter and thickness of a small wafer. Some easily compressible *oily* substance—I employ glaziers' putty—is then rolled out into the form of a slender thread, and a portion of it in this state formed into a ring upon each of the glass discs, in such a manner that a closed cavity may be produced in the centre when the disc is inverted and placed upon a plane surface.—The *Uterus*. Having laid open its cavity, and ascertained, by a careful inspection of its walls, that the ova are not visible with the naked eye, or by means of a pocket lens,—I proceed to remove successive portions of the mucus, beginning with the surface nearest to the Fallopian tube. This is done by scraping it off in small quantities with a broad scalpel, the mucus so removed being carefully transferred to a piece of glass. If this glass be held up to the light and examined with a lens, the observer at once detects an ovum, if present, from its peculiar appearance as a pellucid point, distinguishable from a bubble of air or a globule of oil, by the small refraction of light which occurs at its surface, when viewed in such a medium. If the quantity of mucus which lies above the ovum be too great, it may be removed with a very fine hair pencil, care being taken to avoid touching the ovum itself. A disc of glass furnished with its ring of putty above described, is now to be inverted over the mucus, and slight pressure used. A closed cavity is thus made, which is so minute that in a cool atmosphere no sensible evaporation can take place, and the ovum may be viewed for a considerable time in a nearly unchanged state. The object in having the upper glass *thin*, is to admit the use of magnifying powers having a short focal distance. From the yielding nature of the putty, a compressor—if required—is thus ready formed.—The *Fallopian tube*. The following passage occurs in the paper, before referred to, of the indefatigable CRUIKSHANK†: "Searched in vain for the ova on the right side; at last, by drawing a probe gently over the Fallopian tube on the left side, before it was opened, more than an inch on the side next the uterus, I pressed out several ova, which seemed to come from about its middle, as I began the pressure there, and the ova did not appear till the very last." Yet CRUIKSHANK himself seems not to have applied this method in any other instance, for he subsequently mentions that some of the ova of another Rabbit "were lost from the great difficulty in slitting up the Fallopian tubes without bruising the ova with the fingers or with the point of scissors‡." To the casual mention by CRUIKSHANK, of an alternative resorted to by him on one occasion,—which seems to have remained unnoticed for nearly half a century,—I am indebted for a mode of obtaining ova from the Fallopian tube, that—with some modifications—I now always practise; and which, had I used it from the first, would have enabled me to include in the

† *L. c.*, p. 208, Experiment XXIII.

‡ *L. c.*, p. 208.

Table hereafter given (par. 319.) a much larger number of ova from that narrow passage. I never lay the tube open. Having with fine scissors removed all the adherent substance,—taking care not to apply pressure to the tube at any part,—I extend it in its whole length, divide it in the middle, and proceed to examine the uterine or ovarian half, according to the age of the ova. This is done by cutting off a small portion—say half an inch—of the unopened tube, and pressing out its contents upon a piece of glass with a scalpel. (It is probable that some ova are thus destroyed. But this is of no consequence at all, when we recollect the time saved, and the difficulty in obtaining ova by any other means.) The glass containing the mucus from the portion of Fallopian tube, is then to be held up to the light and examined with a lens as before. If from the minuteness of the ova a lens is insufficient, the mucus may be examined in the microscope with a low power,—say twenty-five diameters,—when the ova if present cannot fail to be detected, whatever their minuteness. It not unfrequently happens that several present themselves in the same field of view. When the mucus is found to contain an ovum, the little disc of glass with its plastic ring should be *instantly* applied, to prevent evaporation†.

Second Postscript.

Process by which the primitive Ovum undergoes Division and Subdivision.—Probable Analogy in this respect between the Mammiferous Ovum and the Ovum of Batrachian Reptiles and certain Fishes.—The so-called "Yelk-ball" in the Mammiferous Ovum compared with the "Discus vitellinus" in the Ova of other Animals.—Resemblance between the fecundated Ovum of Mammalia and that of certain Plants.

314. In reference to the mode in which the successive groups of vesicles are produced in the centre of the ovum during its passage through the Fallopian tube, I ventured to suggest (par. 307.) "that in the interior of each vesicle there arise two or more infant vesicles, the parent vesicle in each instance disappearing by liquefaction." Such really is the case, as proved by the condition of ova which I have met with since.

315. In Plate VI. fig. 105½ is exhibited an ovum of twenty-four hours (from the Fallopian tube), which in reference to its central part was in a condition between the stages seen in figs. 105 and 106‡. The "yelk-ball" (fig. 105.) having—as such—disappeared, *two* vesicles (fig. 105½.) occupied its place; and in another ovum, instead of two corresponding vesicles, *four* (fig. 106.) were found in the same situation.

† Care must be taken that the surface of the glass is dry, and that none of the mucus insinuates itself under the putty. I have in more than one instance preserved the ovum in cold weather for a length of time, which far exceeded expectation. The distance between the two glasses should little exceed the diameter of the ovum, by which the included air is reduced to a very minute quantity.

‡ The chorion was less advanced than in the ovum fig. 105.

316. Each of the *two* vesicles in the centre of the ovum (Plate VI. fig. 105½.) was elliptical and flattened, highly transparent, exhibited a very sharp black contour, and contained a transparent fluid, granules, and a spherical pellucid object having a central situation†. A description in many respects the same has been given (par. 174.) of the *four* vesicles in fig. 106.

317. "That in the interior of each vesicle there arise two or more infant vesicles," we have a proof in Plate IX. fig. 155. Here two outer vesicles are seen corresponding to the two which occupied the centre of the ovum Plate VI. fig. 105½‡. The age of the ovum Plate VI. fig. 105½. was 24 hours; that of the one from which Plate IX. fig. 155. was taken, 26¼ hours. In each of the two vesicles occupying the centre of the ovum Plate VI. fig. 105½. there were seen (as already stated) granules and a central pellucid sphere; while each of the corresponding vesicles in Plate IX. fig. 155. presented in its interior formed *vesicles*. There can be no doubt that the ovum, the central part of which is represented in Plate IX. fig. 155, was in a state between the conditions of the ova in Plate VI. figs. 105½ and 106; and it is extremely probable that before the production of the state seen in Plate VI. fig. 106, the membranes of two vesicles, such as the outer ones in Plate IX. fig. 155, usually disappear by liquefaction. This process continued, would produce successively states such as those in Plate VI. figs. 107 and 108§; and perhaps it would not be easy to point out the period of its termination.—The position which the germinal vesicle should be considered to occupy in the history of "cells," remains a question not yet solved. If a "Cytoblast" (par. 290. and its last Note), corresponding to that which I find on the vitellary membrane in the ovum of the Frog, is originally present in the ovum of other animals (par. 292. and Note), the germinal vesicle is obviously an infant "cell" in reference to the vitellary membrane (*f*.). But we have seen that in the mammiferous ovum a membrane (*e*) forms around the "yelk," in the same manner apparently as in other situations a membrane or "cell" forms around its nucleus. Now it is known that the germinal vesicle exists before the granules and globules of the "yelk;" those granules and globules collecting and perhaps forming around the germinal vesicle. If, therefore, the "yelk" be a nucleus to the membrane *e*, the germinal vesicle may, perhaps, be considered a *nucleolus* to the "yelk." This would afford an instance of a "cell" (the germinal vesicle) which had probably arisen from a "cytoblast" (the germinal spot), becoming in its turn a nucleolus for the formation of another "cytoblast" (the yelk), which then originates another "cell" (the mem-

† These pellucid objects from some cause very soon disappeared, and the two vesicles containing them became comparatively opake. This I have found to occur in many ova of the same period, as well as in ova of the succeeding stages; though no pressure had been applied. The vesicles occupying the centre of ova in a stage approaching that in Plate VI. fig. 108., for instance, at first highly transparent, speedily became opake, and seemed to collapse from a spherical into a polyhedral form.

‡ In some instances the difference in size of these vesicles is considerable.

§ The ingenious speculations of Schwann and Bischoff (par. 307. *Note*.), seem thus in some degree to have been realized.

brane *e*). Within the parent "cell" or membrane *e* new vesicles arise†; the interior of each of these in its turn presenting others. How far the process forming these new vesicles resembles that just referred to as appearing to produce the parent "cell" or membrane *e*, must be left for future observation to decide. We cannot but observe, however, a resemblance between the contents of the infant and the parent "cell"; a resemblance the more interesting from the long line of objects through which it seems traceable in direct succession from the ovum‡.

318. We are now perhaps prepared to realize an analogy already hinted at (pars. 177. 307.), between the early changes which I find to occur in the mammiferous ovum and those previously known to take place in the ovum of Batrachian Reptiles, and some osseous Fishes. The divisions and subdivisions occurring in the ova of these animals, may be effected by a process corresponding to that just described as producing similar changes in the ovum of the Mammal. And if in the former no "outer vesicle" nor pellucid sphere has yet been seen, or suspected, to arise and then disappear between each division, this affords no proof of the non-existence of such objects,—which possibly may yet be discovered. In Fishes the divisions in question do not include the whole yelk-ball, but are confined to a projection on one side§. In the Frog those divisions include the whole of the yelk-ball, but they begin, and proceed more vigorously, on one side‖. In Mammalia also, as we have seen, the divisions include the whole of the so-called "yelk-ball." This comparison may perhaps assist us in

† The aborted ovum, Plate VIII. fig. 144, exhibited what I apprehend to have been the membrane *e* risen in the above manner (at the surface of the "yelk-ball"), but which did not disappear by liquefaction, and was persistent (considerably thickened) until two vesicles had been formed within it (and likewise thickened), each of these presenting a granulous mass in its interior.

‡ Where, indeed, does this resemblance terminate? We find that it has by no means disappeared in the "cells" (Plate VIII. figs. 130. 129.) which seem to enter into the formation of the amnion, nor in those of the lamina subsequently vascular (figs. 132. 150.); and an eminent observer—VALENTIN—has pointed out a resemblance still more remarkable between the ovum and his "Bildungskugeln" in various parts of the nervous system (Ueber den Verlauf, &c., pp. 146, 147. tab. VII. to IX.). The germinal vesicle-like objects in Plate VI. figs. 120. 121., Plate VIII. figs. 129. 130. 132. and 150.—called "nuclei" in the foregoing memoir—I am disposed to think are really *nucleoli*, for the reason above given regarding the germinal vesicle itself; the granules or globules surrounding them (Plate VIII. figs. 130. 150.) being perhaps the remains of a nucleus, in other instances (figs. 129. 150.) dissipated. We find also that in those germinal vesicle-like objects a minute point,—probably a "cytoblast"—was present in some instances, and had been absorbed (?) in others (par. 318. *Note.*).

§ As observed by RUSCONI in the Tench and Bleak (*Cypr. Tinca* and *alburnus*). MÜLLER's Archiv, 1836, Heft III. and IV. Tab. XIII.

‖ VON BAER, MÜLLER's Archiv, 1834, Heft VI. Tab. XI. RUSCONI, MÜLLER's Archiv, 1836, Heft II. Tab. VIII. In connexion with this subject it is interesting to notice the situation of the germinal vesicle, when last seen, in the ovum of the Frog. It lies under the black layer, where—as a flaccid and flattened object—it occupies nearly half of the entire ovum. (See a very mature ovarian ovum of the Frog represented by R. WAGNER (Beiträge, &c., Tab. II. fig. 6. *d.*), in which the germinal vesicle had become much enlarged.) Now it is in this part of the ovum of the Frog that the divisions above referred to commence and most vigorously proceed. (RUSCONI, MÜLLER's Archiv, 1836, Heft II. Tab. VIII. BAER, MÜLLER's Archiv, 1834, Heft VI. Tab. XI.) See also what has been above stated regarding the projection, and the divisions occurring in this projection only, in the ovum of certain Fishes.

determining what portion it is of the ova of the animals just mentioned which corresponds to the "yelk-ball" in Mammalia. Is not the "discus vitellinus" in the *ovarian* ovum of the Bird the seat of similar divisions†? If so, it will perhaps appear that the so-called "yelk-ball" in the mammiferous ovum corresponds more particularly to the "discus vitellinus" (with its germinal vesicle) in the ovum of the Bird (par. 122. and *Note.* par. 174. and first Note.)‡.

† Do they not occur in the corresponding parts of ova in general?

‡ If the contents of the ovarian vesicle of BAER in Mammalia correspond to no more than the "discus vitellinus" in the ovarian ovum of Birds and other animals, the former will not appear to be relatively so minute as hitherto supposed. As to the difference in form of these two objects, perhaps a globular form of the substance composing the "discus vitellinus" would have been incompatible with its position under the vitellary membrane and with the presence around it—in the ovum of the Bird for instance—of a large quantity of true yelk, provided for a future purpose; while no such provision being required in the ovum of the Mammal, the substance corresponding, as I suppose, to the "discus vitellinus" of other animals fills the vitellary membrane (*f*), and is therefore globular in form. If the analogy in question really exists, the "discus vitellinus" is obviously a nucleus destined to undergo changes like those occurring in the so-called "yelk-ball" of the Mammalia. The round white spot called the "cicatricula" in the Bird's *laid* egg may possibly correspond to my layer of "cells," Plate VI. figs. 111 to 113, lining the vitellary membrane (*f*) in the *uterine* ovum of the Mammal; while my "mulberry-like object," in the same figures, may perhaps be represented in the Bird's *laid* egg by the structure which lies under the "cicatricula," and has been denominated Keimhügel, cumulus proligerus, Kern des Hahnentrittes, nucleus cicatriculæ s. blastodermatis, &c.

In reference to the subject of par. 317. and its last note, it may be added, that my view of the germinal vesicle as a *nucleolus* accords with the experience of SCHLEIDEN and of SCHWANN, that the nucleolus exists before the nucleus (par. 297.). The opinion expressed in the last note to par. 317, that the germinal vesicle-like objects called "nuclei" in the foregoing memoir are in strictness *nucleoli*, is applicable to the corresponding objects in previous conditions of the ovum;—for instance, in such as that exhibited in Plate VI. fig. 105½. Each of the twin "cells" here seen contained a *single* germinal vesicle-like object. In an ovum rather more advanced, but not yet in the state Plate IX. fig. 155, I saw *two* such germinal vesicle-like objects in the same twin "cell." And there seems to be a period in the life of each "cell" (Plate VI. figs. 105½, 106, 107, 108.) when the single germinal vesicle-like object disappears. Do two or more (the nucleoli of new and infant "cells") then arise as its successors? In two instances germinal vesicle-like objects were observed in a state of the ovum resembling that in Plate IX. fig. 155.; and one or two of them presented a dark point, which possibly was a germinal spot-like "cytoblast." VALENTIN compared an object observed by him in his "germinal vesicle-like nuclei" to the germinal spot. In one instance (Ueber den Verlauf, &c. tab. IX. fig. 73.) he has figured this object as surrounded by a circle. Had the circle been produced by a process of the same kind as that which effected the change in the germinal spot itself, seen in Plate V. figs. 89 *b*. (par. 124. 299.)? The fact that the germinal spot becomes hollow in certain states (Plate V. figs. 89, 93, 97, 102 *b*.) is interesting in connection with the experience of SCHWANN (regarding other "cytoblasts") referred to in par. 297.—The layer of "cells" lining the membrane *f*, not yet present in the ovum Plate VI. fig. 110, had made its appearance in the ovum fig. 111. Perhaps the "cells" of that layer arose from a continuation of the same process of division referred to in par. 317. (Two germinal vesicle-like objects (nucleoli) it will be remembered (par. 180.) were seen in one of the "cells" fig. 110.) If so, it may be asked,—in connection with what we have seen to take place within the parent cell (the membrane *e*),—does not this process of division admit of a more extended application in the history of "cells," than merely to the "cells" which are the immediate successors of the parent "cell" or membrane *e*? It is extremely interesting to find apparently the same process in operation at a corresponding period in the fecundated *vegetable* ovum. Such at least is the inference I draw from the delineations given by SCHLEIDEN (WIEGMANN's Archiv, 1837, Tab. VII.; and London and Edinburgh Philosophical Ma-

319. *Ova found in the Fallopian Tube and Uterus of the Rabbit.*

The following Tables may, perhaps, facilitate the discovery of the minuter ova in the Rabbit by affording a general idea of their locality and size at different periods. But they also serve to show that in both of these respects the ova of different individuals are subject to variation, partly occasioned, perhaps, by differences in the degree of advancement in the rut. They farther show that there frequently exist considerable differences in the size and condition of ova destined to constitute the same litter of young; that there is no fixed relation between the size of the minuter ova and the degree of their development or their locality; and lastly that ova are not unfrequently aborted.

Ova found in the Fallopian Tube of the Rabbit.

Hours *post coitum*.	Number of ova found.	Diameter in fractions of a Paris line.	Condition.	Locality.
Hours.				
10	2	$\frac{1}{13}$ and $\frac{1}{14}$	Third stage	One inch from the infundibulum.
17	6	$\frac{1}{14}$ to $\frac{1}{10}$	Varying from stage three to the condition represented Plate IX. fig. 153.	Near the middle of the tube.
23	6	$\frac{1}{12}$	Plate VIII. fig. 143.	Where the tube suddenly diminishes in its calibre.
		$\frac{1}{14}$ to $\frac{1}{12}$	Various stages	
24	4	$\frac{1}{12}$ to $\frac{1}{11}$	Plate VI. fig. 105½	Middle of the tube.
26	5	$\frac{1}{11}$ to $\frac{1}{10}$	Plate IX. fig. 155. Apparently aborted	Ovarian side of the middle of the tube.
26¼	4	$\frac{1}{10}$ to $\frac{1}{8}$	Plate IX. fig. 155, and Plate VI. fig. 105½	Ovarian side of the middle of the tube.
34¼	13	$\frac{1}{10}$ to $\frac{1}{6}$	Various stages.	From the middle of the tube to within ½ an inch of the uterus.
35¾	6	$\frac{1}{10}$ to $\frac{1}{8}$	Fifth and sixth stages.	Between the middle and the uterine extremity of the tube.
41	3	$\frac{1}{12}$ — to $\frac{1}{12}$	Fourth stage	Throughout the tube.
44¼	9	about $\frac{1}{8}$	Eighth stage	Near the middle of the tube.
47½	7	$\frac{1}{11}$ to $\frac{1}{8}$	The central portion of the ovum in the seventh and eighth stages. The chorion in the fifth stage, and in one instance still less advanced	Uterine side of the middle of the tube.
48	14	$\frac{1}{8}$ to $\frac{1}{7}$	Between eighth and ninth stages	Near the middle of the tube.
63	1	$\frac{1}{7}$	Ninth stage	One inch from the uterus.
63	4	$\frac{1}{8}$	Fifth stage	Middle of the tube.
65½	2	$\frac{1}{11}$ and $\frac{1}{10}$	Second stage	Two inches from the uterus.
68¾	7	$\frac{1}{7}$ to $\frac{1}{5}$	Tenth stage	¼ inch from the uterus.
	93			

gazine, vol. xii. 1838, Plate 3.) of the incipient "Embryo" in several plants. The resemblance between those delineations and certain states of the mammiferous ovum in the Fallopian tube is very striking; and it is one for observing which I believe no previous opportunity has been afforded. With my drawings Plate VI. figs. 105.

Some of the Ova found in the Uterus of the Rabbit.

Hours *post coitum.*	Number of ova found.	Diameter in fractions of a Paris line.	Condition.	Locality.
Hours. 79½	4	$\frac{1}{7}$	Eleventh stage	Near the tube.
86	9	$\frac{1}{6}$ to $\frac{1}{4}$ +	Twelfth and thirteenth stages	Within an inch of the tube.
94½	4	$\frac{1}{6}$ to $\frac{1}{5}$	Twelfth, thirteenth, and fifteenth stages	Near the tube.
95	4	$\frac{1}{6}$ to $\frac{1}{4}$ +	Two in the eighteenth stage	Near the tube.
97¾	6	$\frac{1}{10}$, $\frac{1}{6}$	Aborted	Near the tube.
		$\frac{1}{7}$ to $\frac{1}{5}$	Sixteenth and seventeenth stages	
102½	9	$\frac{1}{7}$ to $\frac{1}{4}$	Thirteenth to seventeenth stages	Throughout the uterus.
103	13	$\frac{1}{4}$ to $\frac{2}{5}$	Sixteenth, nineteenth, and other stages	Near the tube.
105	4	$\frac{1}{7}$ to $\frac{1}{5}$	Fourteenth, and other stages	¾ inch from the tube.
107½	9	$\frac{1}{4}$ to $\frac{3}{4}$	Twenty-first, and other stages	All within one inch of the tube.
107½	6	$\frac{1}{8}$	Probably aborted	Near the tube.
		$\frac{1}{5}$ − to $\frac{1}{3}$	Twentieth, and other stages	
108½	10	$\frac{1}{4}$ + to $\frac{1}{3}$ +	Nineteenth, and other stages	Throughout the uterus.
111½	8	$\frac{1}{4}$ + to $\frac{1}{3}$	Twenty-first stage	Near the tube.
112¾	1	$\frac{1}{3}$	?	Near the tube.
114¼	7	$\frac{1}{4}$ + to $\frac{1}{3}$	Twenty-first, and other stages	Near the tube.
114¾	9	$\frac{1}{7}$ to $\frac{1}{4}$	Apparently aborted	Throughout the uterus.
115½	5	$\frac{1}{7}$ to $\frac{1}{5}$	Aborted	Near the tube.
115½	9	$\frac{1}{11}$	Aborted. See Plate VIII. fig. 144	Near the tube.
		$\frac{1}{5}$ − to $\frac{1}{3}$	Various stages	
115¾	9	$\frac{4}{10}$ to $\frac{7}{10}$	Some in nineteenth stage, others much more advanced	Throughout the uterus.
118	7	$\frac{1}{7}$	Apparently aborted	Throughout the uterus.
		$\frac{1}{5}$ to $\frac{5}{11}$	Various stages	
119	10	$\frac{2}{5}$ to $\frac{3}{4}$	Various stages	Throughout the uterus.
120½	5	$\frac{1}{7}$ to $\frac{1}{6}$	Aborted	Upper half of uterus.
124¼	6	1 to 1¼	Stages later than the twenty-first	Upper half of uterus.
131¾	9	$\frac{1}{6}$ and $\frac{1}{3}$	Probably aborted	Upper half of uterus.
		$\frac{2}{3}$ to 1	Various stages	
	163			

105½. 107. 108. respectively, I would compare those of Schleiden figs. 14. 15. (*Œnothera crassipes*) figs. 6. 7. (*Potamogeton lucens*). My figure Plate VI. fig. 105½. shows the foundation of the mammiferous embryo to consist at a certain period of two "cells." According to Schleiden's representation (*l. c.* fig. 15.) such is the case in *Œnothera crassipes*; and here the two "cells" have the same form and general appearance as in the ovum of Mammalia, though germinal vesicle-like objects are not present. The evanescent nature of the latter (already mentioned) may possibly explain their absence in the vegetable figure. Some of my delineations of stages rather more advanced may perhaps admit of comparison with those of Schleiden, in which the "terminal shoots" (*punctum vegetationis* of Wolff) come into view, and the cotyledons begin to make their appearance. The granulous appearance in the interior of the "cell" *e* in certain stages, and in that of its

320. *Table of Measurements.*

The measurements are given in fractions of a Paris line (‴), the micrometer used, one of FRAUENHOFER'S, being divided according to French measure. The French inch (of twelve lines) is to the English inch, as 1·06575 is to 1·00000, or nearly one fifteenth more. Assuming it to be exactly one fifteenth more, the simplest mode of converting the fraction of a French *line* into the fraction of an English *inch*, will be to multiply the denominator of the former by the number 11·25 (or $11\frac{1}{4}$). Thus the actual length of the embryo in figs. 124. 125. and 126. which measured $\frac{1}{4}$ of a Paris line, is found to have been about $\frac{1}{45}$ of an English inch.

When the object is not spherical, it is the long diameter, the measurement of which is given in the Table.

No. of Figure.	Diameters magnified.	Actual Diameters.					
		*bb*¹. Central portion of the Germ.	*bb*². Peripheral portion of the Germ.	Embryo *bb*′. + *bb*².	Mulberry-like Structure.	Membrane *f*.	*Cho.* Chorion.
103 *a*	75	.....	.....	.....	.....	$\frac{1}{12}$	
104 *a*	75	.....	.....	.....	.....	.....	$\frac{1}{12}$
105	75	.....	.....	.....	.....	.....	$\frac{1}{10}$
$105\frac{1}{2}$	75	.....	.....	.....	.....	.....	$\frac{1}{11}$
106	75	.....	.....	.....	.....	.....	$\frac{1}{9}$
109	75	.....	.....	.....	$\frac{1}{23}$	.....	$\frac{1}{7}$
110	75	.....	.....	.....	$\frac{1}{20}$	$\frac{1}{12}$	$\frac{1}{5}$
111	75	.....	.....	.....	.....	.....	$\frac{1}{7}$
112	75	.....	.....	.....	.....	$\frac{1}{10}$	$\frac{1}{5}$ +
113	75	.....	.....	.....	.....	$\frac{1}{12}$	$\frac{1}{7}$
114	50	.....	.....	.....	.....	.....	$\frac{1}{4}$ −
115	50	.....	.....	.....	.....	.....	$\frac{1}{6}$
116	50	.....	.....	.....	.....	.....	$\frac{1}{5}$
117	50	.....	.....	.....	.....	.....	$\frac{1}{6}$
118	36	.....	.....	.....	.....	$\frac{1}{6}$	$\frac{1}{4}$
119	36	.....	.....	.....	.....	.....	$\frac{1}{4}$ +
121 A	50	.....	$\frac{1}{10}$	.....	.....	.....	$\frac{2}{3}$
122	40	about $\frac{1}{4}$					
123	40	$\frac{1}{4}$					
124	40	.....	.....	$\frac{1}{7}$	.....	.....	$\frac{1}{3}$ −
125	120	.....	.....	$\frac{1}{7}$			
126	120	.....	.....	$\frac{1}{7}$			
153	75	.....	.....	.....	.....	.....	about $\frac{1}{10}$

successors (Plate VI. figs. $105\frac{1}{2}$ to 108, &c.), is produced by myriads of minuter and epithelium-like "cells" with which they are filled, as will be shown in drawings on a larger scale to accompany a future paper.

321. Explanation of the Plates.

N.B. In all the figures the same letters denote the same objects; as may be seen by the explanation at the foot of each Plate. The same letters are used as in the "First Series."

b. Germinal spot.

bb. Germ.

bb[1]. Central portion of the germ } Embryo.

bb[2]. Peripheral portion of the germ—"tache embryonnaire" —"area vasculosa." } Embryo.

bb[2'']. Future vascular lamina of the umbilical vesicle.

c. Germinal vesicle.

d. Yelk,—yelk-globules (vesicles),—escaped yelk.

e. Membrane originally investing the yelk—proper membrane of the yelk (which disappears. Compare in Plate VI. fig. 105. with fig. 105½.),—also yelk-ball.

f. Thick transparent membrane of the ovarian ovum—"zona pellucida."

f[1]. Fluid imbibed by the chorion.

g. Peculiar granules (vesicles) of the ovisac.

g[1]. Tunica granulosa.

g[2]. Retinacula.

h. Ovisac.

i. Proper covering of the ovisac,—also *corpus luteum*.

hi. Graafian vesicle (consisting of *h* + *i*).

k. Stroma.

l. Peritoneum.

x. Nucleus—"cytoblast."

am. Amnion.

am.f. Union of the membranes *am*. and *f*.

a. p. Area pellucida.

cho. Chorion, becoming villous in the uterus—villous chorion.

cho[1]. Villi.

PLATE V.

Fig. 81. Common Fowl (*Phasianus Gallus*, Linn.). A very early stage in the formation of the ovum (par. 242.).

Fig. 82. Rabbit (*Lepus Cuniculus*, Linn.). An extremely early stage in the formation of the ovum. Largest vesicle $\frac{1}{100}'''$ (par. 242.).

Fig. 83. Rabbit. A stage in the formation of the ovum rather more advanced than that in the preceding figure. Largest vesicle $\frac{1}{75}'''$ (par. 242.).

Fig. 84. Rabbit. The stage succeeding that in the last figure. Largest vesicle $\frac{1}{40}'''$. (par. 242.).

Fig. 84½. Frog (*Rana temporaria*, LINN.). Nucleus (*x*) on the inner surface of the vitellary membrane. *h*. The ovisac (par. 292.)

Fig. 85. Tiger (*Felis Tigris*, LINN.). An immature ovum (par. 120.) crushed to show the nature of the membrane *f*.

Fig. 86. Tiger. Part of a Graafian vesicle (*hi*) containing an ovum with its tunica granulosa (g^1) and retinacula (g^2). The germinal vesicle has become elliptical by maceration for a short time (par. 124.).

Fig. 87. Tiger. Vesicles of the yelk; the largest $\frac{1}{140}'''$. They contain vesicles in their interior (par. 121. 296.).

Fig. 88. Tiger. An ovum after maceration for a short time (par. 123. 124.). The membrane *f* has become distended, and it has imbibed fluid, which lies between that membrane and the proper membrane of the yelk (*e*). The germinal vesicle and germinal spot are altered by maceration. (See fig. 89.)

Fig. 89. Tiger. The germinal vesicle (*c*) and germinal spot (*b*) of the ovum in the last figure, more highly magnified, to show the effects of maceration for a short time. The germinal vesicle has become elliptical, and the germinal spot has resolved itself into several vesicles with intervening granules (par. 124. 299.).

Fig. 92. Rabbit. The germinal vesicle from a fecundated ovum. The vesicle though ruptured has not collapsed, owing to its now consisting of two membranes (par. 133.).

Fig. 93. Rabbit. An ovum from the ovary in the "first stage" of development. (par. 141.).

Fig. 94. Rabbit. The proper membrane of the yelk ($\frac{1}{40}'''$) from an ovum which seemed on the point of being discharged from the ovary. It has thickened (par. 136.).

Fig. 95. Rabbit. A Graafian vesicle 9¼ hours *post coitum*, about to discharge its ovum. The covering (*i*) of the ovisac is now a thick and highly vascular mass; it being this structure which becomes the corpus luteum (par. 152 to 157.).

Fig. 96. Rabbit. The same on a larger scale, and after being ruptured (par. 153.). This figure shows that the tunica granulosa (g^1) and retinacula (g^2) are discharged with the ovum (par. 150.). The ovum is in the "second stage" of development (par. 141.).

Fig. 97. Rabbit. The same ovum on a larger scale. It is in the "second stage" of development (par. 141.).

Fig. 98. Rabbit. The ovisac as obtained, free from its covering, a few hours after the expulsion of the ovum from the ovary. It presents the orifice ($\frac{1}{4}'''$ in length) through which the ovum escaped (par. 154.).

Fig. 99. Hog (*Sus Scrofa*, LINN.). An ovum in which are seen the effects of incipient absorption *post coitum* (par. 158 to 160.). The yelk (*d*) is becoming fluid, a change which takes place first around the germinal vesicle (par. 159.). Dark globules are seen on the surface of the ovum.

Fig. 100. Hog. An ovum in which absorption (*post coitum*) has proceeded farther than in the last figure. The ovum has become elliptical (par. 158 to 160.).

Fig. 101. Rabbit. An ovisac (found in the ovary *post coitum*) apparently about to be absorbed. The ovum, and the germinal vesicle (*c*) have become elliptical, and the yelk (*d*) is in the state of fluid (par. 158 to 160.).

Fig. 102. Hog. An ovisac found in the infundibulum, apparently in the course of being absorbed (par. 162 to 165. 297.).

PLATE VI.

Fig. 103. Rabbit. α. An ovum of ten hours, and measuring in diameter $\frac{1}{10}'''$, found in the Fallopian tube, at the distance of an inch from the infundibulum. It is in the "third stage" of development (par. 170.). β. The same ovum crushed, to show the strength of the proper membrane of the yelk (*e*), which is unbroken and still contains the yelk, though forced through the ruptured membrane *f*. (par. 171.).

Fig. 104. Rabbit. α. An ovum of forty-one hours, and measuring in diameter $\frac{1}{10}'''$, found about an inch from the infundibulum in the Fallopian tube. It is in the "fourth stage" of development. The chorion (*cho.*) is visible, and closely invests the membrane *f*. β. Another ovum of the same Rabbit found further advanced into the tube. It has been crushed, and shows the chorion (*cho.*) now separated from the membrane *f*. (par. 172.).

Fig. 105. Rabbit. An ovum of 35¾ hours, and measuring in diameter $\frac{1}{10}'''$, found in the Fallopian tube near its middle. It is in the "fifth stage" of development (par. 173.).

Fig. 105½. Rabbit. An ovum of twenty-four hours, and measuring in diameter $\frac{1}{11}'''$, found in the Fallopian tube at its middle part. It is in a state between that represented in fig. 105 and that in fig. 106. (par. 174. *Note*, 315. 316.)

Fig. 106. Rabbit. An ovum of 35¾ hours, and measuring in diameter $\frac{1}{9}'''$, found with the ovum represented in fig. 105. It is in the "sixth stage" of development (par. 174.).

Fig. 107. Rabbit. Vesicles in the centre of an ovum somewhat larger than that in the preceding figure, found in the Fallopian tube. These vesicles are smaller and more numerous than those in the last stage, and larger and less numerous than those in the stage following. They represent the "seventh stage" of development (par. 175. 317.).

Fig. 108. Rabbit. Vesicles in the centre of an ovum from the Fallopian tube, representing the "eighth stage" of development (par. 176. 317.).

Fig. 109. Rabbit. An ovum of sixty-three hours, and measuring in diameter $\frac{1}{7}'''$, found in the Fallopian tube, within about an inch of the uterus. It is in the "ninth stage" of development (par. 178.).

Fig. 110. Rabbit. An ovum of $68\frac{3}{4}$ hours, and measuring in diameter $\frac{1}{5}'''$, found in the Fallopian tube within $\frac{3}{4}$ inch of the uterus. It is in the "tenth stage" of development (par. 180.).

Fig. 111. Rabbit. An ovum of $79\frac{1}{2}$ hours, and measuring in diameter $\frac{1}{7}'''$, found in the uterus near the Fallopian tube. It is in the "eleventh stage" of development (par. 184.).

Fig. 112. Rabbit. An ovum of eighty-six hours, and measuring in diameter $\frac{1}{5}''' +$, found in the uterus within an inch of the Fallopian tube. It is in the "twelfth stage" of development (par. 185.).

Fig. 113. Rabbit. An ovum of $102\frac{1}{2}$ hours, and measuring in diameter $\frac{1}{7}'''$, found in the uterus near its middle. It is in the "thirteenth stage" of development (par. 186. 187.).

Fig. 114. Rabbit. An ovum of 105 hours, and measuring in diameter $\frac{1}{4}'''$, found in the uterus $\frac{3}{4}$ inch from the Fallopian tube. It is in the "fourteenth stage" of development (par. 189.).

Fig. 115. Rabbit. An ovum of $94\frac{1}{2}$ hours, and measuring in diameter $\frac{1}{6}'''$, found in the uterus near the Fallopian tube. It is in the "fifteenth stage" of development (par. 190. 191.).

Fig. 116. Rabbit. An ovum of $97\frac{3}{4}$ hours, and measuring in diameter $\frac{1}{5}'''$, found in the uterus about an inch from the Fallopian tube. It is in the "sixteenth stage" of development (par. 192.).

Fig. 117. Rabbit. An ovum of $97\frac{3}{4}$ hours, and measuring in diameter $\frac{1}{8}'''$, found in the uterus. It is in the "seventeenth stage" of development (par. 193 to 196.).

PLATE VII.

Fig. 118. Rabbit. An ovum of ninety-five hours, and measuring in diameter $\frac{1}{4}'''$, found in the uterus an inch from the Fallopian tube. It is in the "eighteenth stage" of development (par. 197 to 200.).

Fig. 119. Rabbit. An ovum of $108\frac{1}{2}$ hours, and measuring in diameter $\frac{1}{4}''' +$, found in the uterus near the Fallopian tube. It is in the "nineteenth stage" of development (par. 201.).

Fig. 120. Rabbit. A portion of the future umbilical vesicle in an ovum of $107\frac{1}{2}$ hours, and measuring $\frac{1}{3}'''$, found in the uterus $1\frac{3}{4}$ inch from the Fallopian tube. It represents the "twentieth stage" of development (par. 202.).

Fig. 121. Rabbit. A portion of the future umbilical vesicle in an ovum of 111½ hours, and measuring in diameter ¼‴, found in the uterus an inch from the Fallopian tube. It represents the "twenty-first stage" of development (par. 203.).

Fig. 121 A. Rabbit. An ovum of 111½ hours, and measuring in diameter ¼‴, found in the uterus an inch from the Fallopian tube (par. 205. 206.). Drawn as seen lying in kreosote water (par. 239.). The embryo is described in pars. 209. and 212 to 215.

Fig. 121 B. Rabbit. The embryo (bb^1 and bb^2.) and incipient amnion (*am.*). The embryo is in a stage succeeding that in fig. 121 A (par. 212 to 215.).

Fig. 121 C. Rabbit. The most central portion of the embryo in fig. 121 B, on a larger scale (pars. 213. 214.).

Fig. 121 D. Rabbit. The central portion (bb^1) of the germ, from an ovum of 103 hours, and measuring in diameter ⅓‴. *am. f.* Union of the membranes *am.* and *f.*

Fig. 122. Rabbit. The embryo ($bb^1 + bb^2$) and incipient amnion (*am.*) from an ovum of 124¼ hours, and measuring in diameter 1‴ +, found in the uterus (pars. 214 to 216.).

Fig. 123. Rabbit. The central portion of the germ (¼‴ in length) (par. 215.) from an ovum of 164½ hours, and measuring in diameter more than 2¼‴, found in the uterus. This figure presents an instance of size being in advance of development (pars. 167. 218.).

Fig. 124. Rabbit. An ovum of 115½ hours, and measuring in diameter ⅓‴, found in the uterus. The embryo (bb^1) measured in this instance only $\frac{1}{7}$‴ ($= \frac{1}{70}$ of an English inch), thus presenting an example of development being greatly in advance of size (pars. 167. 218.).

Fig. 125. Rabbit. The embryo from the last figure, more highly magnified. It exhibits a tendency to become curved at the cephalic end, and transverse wrinkles, thereby produced (par. 219.).

Fig. 126. Rabbit. The same, as seen after slight pressure had been applied (par. 219.).

Fig. 127. Rabbit. The visceral surface of the foundation of the central portion of the nervous system and vertebræ in an embryo of rather less than 1½‴, from an ovum of 8½ days, and measuring in diameter 6‴ +, found in the uterus (par. 217.).

PLATE VIII.

Fig. 128. Rabbit. The ovum of Plate VI. fig. 109, after being crushed. The dotted line denotes the inner surface of the subsequently villous chorion (*cho.*) (par. 178.).

Fig. 129. Rabbit. Vesicles of the future amnion, from an ovum of $94\frac{1}{2}$ hours, and measuring in diameter $\frac{1}{4}'''$, found at the junction of the uterus and Fallopian tube (par. 190.).

Fig. 130. Rabbit. An ovum resembling that in Plate VI. fig. 110, after being crushed (par. 180.). The dotted line denotes the inner surface of the subsequently villous chorion (*cho.*) (par. 178.). Compare this ovum with fig. 131. from *Unio tumida* (par. 243.).

Fig. 131. From Carus. An ovum from the gills of *Unio tumida*. Compare with fig. 130. from the Rabbit (par. 243.).

Fig. 132. Rabbit. A portion of the network of which the subsequently vascular lamina of the umbilical vesicle consists in the "nineteenth stage" of development (Plate VI. fig. 119.) (par. 201.).

Fig. 133. Rabbit. An aborted ovum, found in the uterus (par. 226.).

Fig. 134. Rabbit. An aborted ovum, found in the uterus (par. 226.).

Fig. 135. Rabbit. An aborted ovum, found in the uterus (par. 226.).

Fig. 136. Rabbit. A vesicle, found in the Fallopian tube with others of the same kind (par. 227.).

Fig. 137. Rabbit. An ovum of $162\frac{3}{4}$ hours, and measuring in diameter $\frac{7}{16}'''$, found in the uterus. It is in a collapsed state from the effects of water (par. 231.).

Fig. 138. Rabbit. An ovum of $\frac{9}{16}'''$, drawn after lying three days in kreosote water (par. 239.).

Fig. 139. Rabbit. An ovum of $\frac{3}{4}'''$, drawn after lying four days in tar water (par. 241.).

Fig. 140. Rabbit. An ovum of $\frac{1}{4}'''$, showing the effects of nitrate of silver (par. 238.). The objects presenting in this ovum the appearance of a network, are vesicles such as those in Plate VIII. fig. 150.

Fig. 141. Rabbit. Villous tuft, measuring in diameter $\frac{1}{32}'''$, as seen on the chorion of an ovum from the uterus, measuring $\frac{7}{16}'''$ (par. 223.).

Fig. 142. Rabbit. Villous tufts seen in profile on the chorion (*cho.*) of an ovum from the uterus, measuring in diameter $\frac{7}{16}'''$ (par. 223.).

Fig. 143. Rabbit. An ovum of 23 hours, and measuring in diameter $\frac{1}{16}'''$, found in the Fallopian tube (par. 306.).

Fig. 144. Rabbit. An aborted ovum of $115\frac{1}{2}$ hours, and measuring in diameter $\frac{1}{11}'''$, found in the uterus (par. 308. and *Note.* 317. *Note.*). It is in a state which, in reference to the central portion of the ovum, is between that represented in Plate VI. fig. 105. and that in fig. $105\frac{1}{2}$.

Fig. 145. Rabbit. An ovum of $114\frac{1}{4}$ hours, and measuring in diameter $\frac{1}{2}'''$, found in the uterus. The membrane *am.* is adherent at a certain part to (*f*) the thick transparent membrane of the ovarian ovum (pars. 206. 208.). Drawn after lying six weeks in dilute spirit (par. 233.).

Fig. 148. Rabbit. The germ in its vesicle, as seen within the (imperfectly formed) mulberry-like structure while still in the centre of the ovum. The incipient separation of the germ into a central (bb^1) and a peripheral (bb^2) portion appeared to have been premature (par. 193. *Note*).

Fig. 149. Rabbit. Vesicles of which the incipient embryo was composed, in an ovum of 111½ hours, and measuring in diameter $\frac{1}{5}'''$, found in the uterus an inch from the Fallopian tube (par. 301. 305.). Drawn after lying 48 hours in kreosote water (par. 239.).

Fig. 150. Rabbit. Vesicles of the outer and subsequently vascular lamina of the umbilical vesicle, from an ovum of 107½ hours, and measuring in diameter $\frac{1}{5}''' +$, found in the uterus near the Fallopian tube (par. 211.). The interior of these vesicles was brought into view by nitrate of silver (par. 238.).

PLATE IX.

Fig. 151. Rabbit. A vesicle found under the mucous membrane at the junction of the uterus and Fallopian tube. The mulberry-like object in its centre was observed for half an hour to perform rotatory motions (pars. 282 to 287.).

Fig. 152. Rabbit. Vesicles from the surface of the mulberry-like object found in vesicles such as the one in fig. 151. (par. 285.)

Fig. 153. Rabbit. An ovum of 17 hours, and measuring in diameter about $\frac{1}{10}'''$, found in the Fallopian tube near its middle (par. 173. *Note*. 221. to 225.).

Fig. 154. Rabbit. Vesicles found in a cream-white substance, filling to distention the left uterus, 157¾ *post coitum*. This substance—at first of about the same consistence as pus—coagulated very shortly after the uterus had been laid open. The vesicles varied in size from $\frac{1}{600}'''$ to $\frac{1}{300}'''$, most of them measuring about $\frac{1}{400}'''$.

Fig. 155. Rabbit. Two vesicles from the centre of an ovum of 26½ hours, and measuring in diameter about $\frac{1}{10}'''$, found in the Fallopian tube on the ovarian side of its middle part. This figure represents a condition of the ovum between that in Plate VI. fig. 105½, and that in fig. 106 (par. 317.).

XX. *Researches in Physical Geology. By* W. Hopkins, *Esq. M.A. F.R.S., Fellow of the Royal Astronomical Society, of the Geological Society, and of the Cambridge Philosophical Society.—First Series.*

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On the Phenomena of Precession and Nutation, assuming the Fluidity of the Interior of the Earth.

§. *Preliminary Observations on the Refrigeration of the Globe.*

BEFORE I proceed to the discussion of the question which forms the principal subject of the present communication, I shall offer some general remarks on the refrigeration of the globe, as introductory not only to this memoir, but to others which I hope hereafter to bring under the notice of the Society.

In the first place, we may observe that there are two distinct processes of cooling, of which one belongs to bodies which are either solid or imperfectly fluid, and is termed cooling by *conduction*, and the other to masses in that state of more perfect fluidity which admits of a free motion of the component particles among themselves. In this case the cooling is said to take place by *circulation* or *convection*. The nature of the former process has been ascertained with considerable accuracy by experiment, and the laws of the phenomena have been made the subject of mathematical investigation, but of the exact laws of cooling by the latter process we are comparatively ignorant. It is manifest, however, that since *time* must be necessary for the transmission of the hotter and lighter particles from the central to the superficial parts of the mass, as well as for that of the colder and heavier particles in the opposite direction, the temperature must increase with the depth beneath the surface; and, moreover, that this increase will be the more rapid, the more nearly the fluidity of the mass approaches that limit at which this process of cooling would cease, and that by conduction begin, since the rapidity of circulation would constantly diminish as the fluidity should approximate to that limit. But still, even in this limiting case, it seems probable that the tendency to produce an equality of temperature throughout the mass will be much greater, and consequently the rate of increase of temperature in approaching the centre much less, than if the cooling of the mass had proceeded by conduction during the same time, the conductive power being very small.

If the matter composing the globe was originally in a high state of fluidity from heat, the process of cooling would undoubtedly, in the first instance, be by circulation. The manner in which the transition will take place from this mode of refri-

geration to that by conduction, depends on certain conditions, of which, in our speculations on this subject, it is important to form a distinct conception.

Since the heat increases with the distance from the surface while the mass is cooling by circulation, the tendency to solidification, so far as it depends on this cause, will be greatest at the surface and least at the centre; but, on the other hand, the pressure is least at the surface and greatest at the centre; and consequently the tendency to solidify, as depending on this cause, will be greatest at the centre and least at the surface. To estimate this tendency under the joint influence of these causes, it would be necessary, in the first place, to know the law according to which the temperature increases in descending from the surface to the centre, while the mass is cooling by circulation; and secondly, the influence of the temperature in resisting solidification, as compared with that of the pressure in promoting it. These, however, are points on which we possess at present little or no experimental evidence, and therefore the only conclusion at which we can arrive is this,—that if the augmentation of the temperature with that of the depth be so rapid, that its effect in resisting the tendency to solidify be greater than that of the increase of pressure to promote it, there will be the greatest tendency to become *imperfectly fluid*, and afterwards to solidify in the superficial portions of the mass; whereas if the effect of the augmentation of pressure predominate over that of the temperature, this transition from perfect to imperfect fluidity, and subsequent solidity, will commence at the centre.

If we suppose the former of these cases to hold, it would appear that no incrustation of the surface could take place so long as any inferior portion of the mass retained its perfect fluidity, because as the superior particles should become condensed they would continually descend into the perfect fluid beneath, always supposing the mass in that state in which an increase of specific gravity would result from a decrease of temperature. The process of circulation would thus go on till every part of the mass should have lost that degree of more perfect fluidity, which admits of a motion of the particles among themselves being excited by their unequal refrigeration. The circulation, therefore, would cease nearly contemporaneously in every part of the mass, which would then begin to cool by conduction, rapidly at the surface exposed to the low temperature of the planetary space, and extremely slowly in the central parts, on account of the small conductive power of the matter composing the earth. Consequently the globe would consist, after a certain time, of an exterior solid crust, and interior fluid matter, of which the fluidity would increase in approaching the centre, where it might still approach to that more perfect fluidity which admits of cooling by convection. With reference, however, to the mechanical action of any forces producing either motion or hydrostatic pressure in the interior mass, the whole of it might, as an approximation, be considered perfectly fluid. No attempt has yet been made to determine the present probable thickness of the earth's crust, assuming it to have been originally in a state of fluidity, on account of the difficulty already mentioned, arising from our ignorance of the influence of high temperature in resisting

solidification, compared with that of great pressure in promoting it. All that has hitherto been determined on the subject is, that the present state of the earth's surface may be consistent with the existence of a solid crust, of which the thickness is small compared with the earth's radius.

Let us now recur to the other case above mentioned, that in which the increase of pressure in descending towards the centre of the mass is supposed to have a greater effect in promoting solidification than the increase of temperature in preventing it. Supposing the mass to have been first in a state in which every part was cooling by convection, this process would first cease, and that of cooling by conduction begin at the centre, while the superior portion would still continue to cool by convection, so that these two processes would for a time be going on simultaneously in different parts of the mass. It is manifest, however, that the central portion, cooling by conduction, would constantly increase, while the exterior portion, cooling by convection, would constantly diminish, so that at length no part of the mass would be cooling by the latter process. Before it should reach this stage of the refrigeration the central portion of a mass so large as the earth might become perfectly solid, so that at the instant when the circulation should entirely cease, the whole might consist of a solid central nucleus, surrounded by the external portion still in a state of fusion, and of which the fluidity would vary continuously from the solidity of the nucleus to the fluidity of the surface, where, at the instant we are speaking of, it would be just such as not to admit of circulation.

When the mass should have arrived at this stage of the cooling, a change would take place in the process of solidification, which it is important to remark. The superficial parts of the mass must in all cases cool the most rapidly, and now (in consequence of the imperfect fluidity) being no longer able to descend, a *crust* will be formed on the surface, from which the process of solidification will proceed far more rapidly downwards, than upwards on the solid nucleus. Consequently, then, our globe would arrive at that state, according to the mode of cooling we are now considering, in which it would be composed of a solid shell, and a solid central nucleus, with matter in a state of fusion between them, the fluidity of which, however, would necessarily be less than that which might exist in the fused mass very near the centre in the case previously considered.

With respect to the thickness of the shell which may be consistent with the present appearances of the earth's surface, the same conclusion will hold as in the former case, i. e. it may be small compared with the earth's radius. What would be the radius of the solid nucleus at the instant of the first incrustation of the surface, or that which would correspond to any assigned thickness of the exterior shell, it is quite impossible to determine from the want of all experimental evidence respecting the tendency of great pressure to promote solidification at very high temperatures, and our ignorance of the temperature at which the superficial incrustation of a large mass would begin, when exposed to the temperature of the planetary space. It is, therefore, manifestly

impossible to decide by any such reasoning as the above, whether the exterior shell and solid nucleus are now united, or are separated by matter still in a state of fusion*.

Upon the whole, reasoning such as the above can lead us to nothing more definite than the following conclusions respecting the actual state of the earth, assuming it to have once been in a state of perfect fluidity.

(1.) It may consist of a solid exterior shell and an internal mass in a state of fusion, of which the fluidity is greatest at the centre; and it is possible that the thickness of the shell may be small compared with its radius, and the fluidity at the centre may approximate to that which would admit of cooling by convection.

(2.) It may consist of an exterior shell, and a central solid nucleus, with matter in a state of fusion between them. The thickness of the shell, as well as the radius of the solid nucleus, may possibly be small compared with the radius of the earth. The fluidity of the intervening mass must necessarily be considerably more imperfect than that which would just admit of cooling by circulation.

(3.) The earth may be solid from the surface to the centre.

It appears then that the direct investigation of the manner of the earth's refrigeration, assuming its original fluidity from heat, still leaves us in a state of perfect uncertainty as to the actual condition of its central parts, not from any imperfection in the mathematical part of the investigation, but from the want of the experimental determination of values which it must ever be found extremely difficult, if not impossible, to obtain with accuracy. Under these circumstances, we are naturally led to consider whether any other more indirect test may be found of the truth of the hypothesis of central fluidity. In reflecting on this subject, it occurred to me some time ago, that such a test might possibly be found in the delicate but well-defined phenomena of precession and nutation. The connexion between these phenomena and the interior fluidity will at once be seen by those accustomed to physical investigations of this nature; since it is manifest, that the direct action of those forces which produce the precessional motion of the earth's pole must be entirely different on the interior part of the earth, if that part be fluid, to that which must be exerted, if the interior part be solid. It becomes, therefore, a matter of interest to examine how far the internal

* M. Poisson, was, I believe, the first to advocate the hypothesis of the solidification of the earth having commenced from the centre, and has stated in general terms that, in such case, it would proceed to the surface which would be the last to solidify (Théorie de la Chaleur, p. 428.). It is manifest, however, from what has been advanced, that this could not be literally correct, but that the solidification must necessarily commence at the surface before the whole internal portion had become solid. The distinction is of little consequence as respects the object which M. Poisson had in view, but is of the highest importance with reference to Geological speculation, because it shows, that, supposing the earth once to have been fluid, it must be now or have been at some antecedent epoch in that state in which a solid exterior crust rests on an imperfectly fluid and incandescent mass beneath. It forms no part of my immediate object, to consider whether the hypothesis of this being or having been once the state of our planet, best enables us to account for the igneous matter which has been injected so generally into the sedimentary portion of the earth's crust, but it is important to know, that this state of the earth, assuming its original fluidity, is one through which it must necessarily have passed in the course of its refrigeration, whatever might be the process of its solidification.

fluidity may consist with the observed phenomena of the precessional motion of the pole. These phenomena have been shown to be perfectly in accordance with the internal solidity of the earth under certain hypotheses, which may be deemed perfectly reasonable, respecting the law of density; but so far from any attempts having been hitherto made to determine what would be the precessional motion on the supposition of interior fluidity, I am not aware that the problem has been before suggested. I shall now proceed to its solution, which forms the principal object of the present memoir.

On Precession and Nutation; assuming the Fluidity of the Interior of the Earth.

In the present memoir I shall investigate the amount of the luni-solar precession and nutation, assuming the earth to consist of a solid spheroidal shell filled with fluid. To present the problem under its most simple form I shall first suppose the solid shell to be bounded by a determinate inner spheroidal surface, of which the ellipticity is equal to that of the outer surface, the change from the solidity of the shell to the fluidity of the included mass not being gradual but abrupt. I shall also here suppose both the shell and fluid homogeneous and of equal density. From this I propose in a future memoir to pass to the case in which the earth is considered as heterogeneous.

§. *Statement of the Problem.*

1. If S denote the position of the sun, A the centre of the earth, A P its axis of instantaneous rotation, the sun's attraction tends to produce an angular velocity of the earth about an axis through A, and perpendicular to the plane S A P. The moving force producing this rotation (supposing the earth a homogeneous spheroid),

$$= \frac{3\mu}{2 r_{\prime}^3} \cdot \frac{4\pi}{15} a_{\prime}^2 c_{\prime} (a_{\prime}^2 - c_{\prime}^2) \sin 2\Delta^*,$$

where

$\mu =$ absolute force of the sun's attraction.

$\Delta =$ sun's polar distance.

$r_{\prime} =$ S A.

$a_{\prime} =$ equatorial radius.

$c_{\prime} =$ polar radius.

Also the moment of inertia of the spheroid about the axis of this rotatory motion,

$$= \frac{4\pi}{15} k a_{\prime}^2 c_{\prime} (a_{\prime}^2 + c_{\prime}^2).$$

Consequently the accelerating force of rotation

$$= \frac{3}{2} \cdot \frac{\mu}{r_{\prime}^3} \cdot \frac{a_{\prime}^2 - c_{\prime}^2}{a_{\prime}^2 + c_{\prime}^2} \sin 2\Delta$$

$$= \frac{3}{2} \cdot \frac{\mu}{r_{\prime}^3} \epsilon \sin 2\Delta$$

($\epsilon =$ ellipticity of the spheroid); and if we denote this quantity by α, and the diurnal

* Airy's Tracts, Precession and Nutation.

angular velocity of the earth by ω, the angular velocity of A P about A will $= \frac{\alpha}{\omega}$, the instantaneous motion of P being perpendicular to the plane S A P*.

2. But let us now suppose the spheroid hollow, the hollow part being spherical, and having its centre coincident with that of the spheroid. The moving force of rotation will be unaltered, but the moment of inertia will

$$= \frac{4\pi}{15} k\, a_i^2\, c_i\, (a_i^2 + c_i^2) - \frac{8\pi}{15} k\, r^5$$

(r = radius of the hollow sphere). Therefore α will now

$$= \frac{3}{2} \cdot \frac{\mu}{r_i^3} \cdot \frac{a_i^2 c_i (a_i^2 + c_i^2)}{a_i^2 c_i (a_i^2 + c_i^2) - 2 r^5} \sin 2\,\Delta,$$

which, if r be considerable, will be much greater than its former value.

3. Again, let us suppose this hollow sphere filled with matter in a state of perfect fluidity. The pressures of this fluid on the interior spherical surface of the shell containing it being normal pressures (whatever be the causes producing them), their directions will all pass through the centre of the spheroid, and cannot therefore influence the rotatory motion we are now considering; and since there will be no friction with the assumed perfect fluidity of the interior matter, the value of α will be precisely the same as that above stated, when the internal sphere is entirely empty. A much greater motion of the pole would therefore result from this constitution of the spheroid than if it were perfectly solid; and it would, moreover, be entirely independent of the position of the axis of rotation of the internal fluid.

4. If the internal surface of the solid shell be spheroidal instead of spherical, the directions of the fluid normal pressures will no longer pass through an axis through the centre of the earth; and when the axes of diurnal rotation of the solid shell, and of the internal fluid do not coincide (as must generally be the case from the different actions of the sun and moon on the solid shell and on the fluid contained in it), the fluid pressure arising from the centrifugal force will introduce a new and important element into the calculation of the precessional motion of the pole. I shall now proceed to the determination of this motion on the hypotheses previously stated.

§. *Formation of the Differential Equation for the Motion of the Pole.*

5. Conceive a sphere of radius unity described about the centre of the earth, which centre we shall always denote by A. Let Π (fig. 1.) be the point in which a line through the centre and perpendicular to the plane of the ecliptic meets the sphere; and P and P′ the points in which it is met respectively by the axes of instantaneous rotation of the solid shell and of the internal fluid mass†. Let P and P′ be referred to the small circle O M, of which Π is the pole, and to great circles Π P M, Π P′ M′ respect-

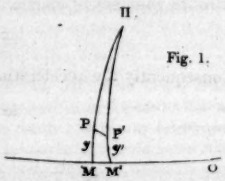

Fig. 1.

* Airy's Tracts, p. 197.

† The axis of instantaneous rotation may be regarded as coincident with the spheroidal axis of the earth;

ively, Π M being very nearly equal to the obliquity of the ecliptic. Take O an arbitrary fixed point in the small circle, and let

$$\mathrm{OM} = x \qquad \mathrm{OM}' = x'$$
$$\mathrm{MP} = y \qquad \mathrm{M'P'} = y',$$

y, y' and $x - x'$ will be in general very small, and may, therefore, be considered as straight lines. Our object will be to form a system of four simultaneous differential equations, the integration of which will give x, y, x', and y' as functions of t. For this purpose I shall first consider the *arguments* of the different terms in the expressions for $\frac{dx}{dt}$, $\frac{dx'}{dt}$, $\frac{dy}{dt}$ and $\frac{dy'}{dt}$, which severally express the effects of the different physical causes affecting the motions of P and P', postponing the calculation of the numerical values of the *coefficients* till we shall have integrated our differential equations, as we shall then have the advantage of knowing what degree of accuracy may be essential in the determination of these values.

I. *The Attraction of the Sun on the Solid Shell.*—This will produce effects of precisely the same kind as if the spheroid were solid, but with different coefficients (Art. 2.), and therefore, if the motion of P depended on this cause alone, we should have

$$\frac{dx}{dt} = \mathrm{A}_1 - \mathrm{B}_1 \cos 2\,(nt + \lambda)$$
$$\frac{dy}{dt} = \qquad \mathrm{D}_1 \sin 2\,(nt + \lambda),$$

(where $nt + \lambda$ is the longitude of the sun at the time t), these being the forms of the expressions which give the precessional motion of the pole, and its motion of nutation as far as they depend on the sun's action.

II. *The Attraction of the Moon on the Shell.*—This alone would give us

$$\frac{dx}{dt} = \mathrm{A}_2 - \mathrm{B}_2 \cos 2\,(n't + \lambda')$$
$$\frac{dy}{dt} = \qquad \mathrm{D}_2 \sin 2\,(n't + \lambda'),$$

where $n' = \frac{\pi}{\text{period of } ☽\text{'s node}}$.

III. *The Interior Pressure on the Shell from the Attraction of the Sun on the Fluid Mass.*—If the whole mass of the earth were perfectly fluid, and its undisturbed form spherical, the attraction of the sun alone would transform this sphere into a prolate spheroid, of which the longer axis would lie in the line through S and A, the centres of the sun and earth; and similarly if the interior surface of the solid shell which we suppose to contain the internal fluid were spherical, the sun's action would tend to make this fluid assume the spheroidal form just mentioned, and would consequently produce a fluid pressure on the interior surface of the solid shell, which

for the greatest angular separation will be of the same order as ϵ . P A P', and may therefore be neglected in comparison with P A P'.

would be equal at all points similarly situated with respect to the line just mentioned through the centres of the sun and earth. If the interior surface of the shell be spheroidal, but of small eccentricity, very nearly the same effect will be produced. The pressure in this case will be exactly equal at points similarly situated with respect to a plane through the sun and the axis of rotation (A P) of the shell, and will consequently tend to communicate a rotatory motion to the shell about an axis perpendicular to this plane and through the earth's centre; *i. e.* about the same axis as that about which the attraction mentioned in (I.) tends to communicate a rotatory motion. Also the effects of this pressure must *recur* with recurring positions of the sun exactly in the same manner as the effects of the sun's attraction just alluded to. Hence the terms depending on this cause will be of the same form as those in (I.), as will, in fact, be proved to be the case when we come to investigate their exact value. They will, therefore, give us

$$\frac{dx}{dt} = A_3 - B_3 \cos 2\,(n\,t + \lambda)$$

$$\frac{dy}{dt} = \qquad D_3 \sin 2\,(n\,t + \lambda).$$

IV. *The Interior Pressure on the Shell from the Attraction of the Moon on the Fluid Mass.*—This will give us terms similar to those arising from the sun's action. From this cause alone, therefore, we should have

$$\frac{dx}{dt} = A_4 - B_4 \cos 2\,(n'\,t + \lambda')$$

$$\frac{dy}{dt} = \qquad D_4 \sin 2\,(n'\,t + \lambda').$$

V. *The Interior Pressure on the Shell from the Centrifugal Force of the Fluid Mass.*—When P and P′ do not coincide, the interior fluid mass will tend, from the effect of centrifugal force, to assume a form different from that of the interior surface of the solid shell. Thus normal pressures will be produced on the interior surface of the shell; and they will manifestly act symmetrically with respect to a plane through P, P′ and A the centre of the earth, i. e. through the axes of rotation of the solid shell and of the fluid mass. Consequently the tendency of these pressures will be to communicate a motion of rotation to the shell about an axis through A, and perpendicular to this plane; and the consequent motion of P, if this force alone acted on the shell, would be perpendicular to P′ P, the axis of rotation of the shell having, from this cause, an angular velocity in space $= \frac{\alpha''}{\omega}$ (Art. 1.) α'', being the quantity analogous to α in the article referred to; or since P and P′ are supposed to be on the surface of a sphere whose radius is unity, $\frac{\alpha''}{\omega}$ will be the *linear* velocity of P perpendicular to P′ P. Now when we come to the calculation of the quantities involved in these investigations, we shall find that $\frac{\alpha''}{\omega} = \gamma_1 \sin 2\,\beta$, where γ_1 is a constant quantity depending on

the diurnal angular velocity (ω), and on the magnitudes and ellipticity of the fluid spheroid and solid shell; and where $\beta =$ the angle P A P′, or $=$ the line P′ P. Consequently,

$$\frac{\alpha''}{\omega} = \gamma_1 \sin 2 \,.\, \mathrm{P'\,P},$$

or, since P′ P will always be extremely small, the linear velocity of P perpendicular to P′ P,

$$= \frac{\alpha''}{\omega} = 2\,\gamma_1 \,.\, \mathrm{P'\,P}\,;$$

and resolving this in directions parallel and perpendicular to M′ M, we have (ψ being the angle which P′ P makes with the axis of x)

$$\frac{dx}{dt} = -\,2\,\gamma_1 \,.\, \mathrm{P'\,P} \,.\, \sin\psi = -\,2\,\gamma_1\,(y - y')$$

$$\frac{dy}{dt} = 2\,\gamma_1 \,.\, \mathrm{P'\,P} \cos\psi = 2\,\gamma_1\,(x - x').$$

6. If we now take the sum of the different terms which express the effects of the several causes affecting the motion of P, we obtain for the complete values of $\frac{dx}{dt}$ and $\frac{dy}{dt}$,

$$\frac{dx}{dt} = (\mathrm{A}_1 + \mathrm{A}_2 + \mathrm{A}_3 + \mathrm{A}_4) - (\mathrm{B}_1 + \mathrm{B}_3)\cos 2\,(n\,t + \lambda) - (\mathrm{B}_2 + \mathrm{B}_4)\cos 2\,(n'\,t + \lambda')$$
$$-\,2\,\gamma_1\,(y - y')\,;$$

$$\frac{dy}{dt} = (\mathrm{D}_1 + \mathrm{D}_3)\sin 2\,(n\,t + \lambda) + (\mathrm{D}_2 + \mathrm{D}_4)\sin 2\,(n'\,t + \lambda')$$
$$+\,2\,\gamma_1\,(x - x')\,;$$

or putting

$$\mathrm{A}_1 + \mathrm{A}_2 + \mathrm{A}_3 + \mathrm{A}_4 = \mathrm{A}$$
$$\mathrm{B}_1 + \mathrm{B}_3 = \mathrm{B}$$
$$\mathrm{B}_2 + \mathrm{B}_4 = \mathrm{B}'$$
$$\mathrm{D}_1 + \mathrm{D}_3 = \mathrm{D}$$
$$\mathrm{D}_2 + \mathrm{D}_4 = \mathrm{D}'$$

$$\left.\begin{aligned} \frac{dx}{dt} + 2\,\gamma_1\,(y - y') &= \mathrm{A} - \mathrm{B}\cos 2\,(n\,t + \lambda) - \mathrm{B}'\cos 2\,(n'\,t + \lambda') \\ \frac{dy}{dt} - 2\,\gamma_1\,(x - x') &= \mathrm{D}\sin 2\,(n\,t + \lambda) + \mathrm{D}'\sin 2\,(n'\,t + \lambda') \end{aligned}\right\} \quad . \quad . \quad (\mathrm{A.})$$

§. *Motion of the Internal Fluid.*

7. When any accelerating forces, X, Y, Z, act upon a homogeneous fluid mass of which the whole surface or any part of it is free, we have two conditions of equilibrium, viz. that $\mathrm{X}\,dx + \mathrm{Y}\,dy + \mathrm{Z}\,dz$ must be a perfect derivation of a function of the three

independent variables x, y, z, and that $X\,d\,x + Y\,d\,y + Z\,d\,z = 0$, must be the differential equation to the free surface. If however no part of the surface of the fluid is free, as when the whole mass is contained in a rigid shell which it entirely fills, the former of these conditions is the only essential one of equilibrium. Also if there be several sets of forces which separately satisfy this condition when referred to different systems of coordinate axes, it will manifestly be satisfied by all these sets of forces taken conjointly; and if any proposed set of forces do not satisfy it, we may still omit, in the determination of the motion resulting from these forces, those terms in the expressions for X, Y, and Z, which taken conjointly do satisfy the analytical condition now spoken of. These considerations will materially simplify the following investigations.

8. We have now to consider the tendency of the forces acting on the internal fluid to put it in motion.

I. *Disturbing Force of the Sun.*—Let x, y, z be the coordinates of any particle (Q) of the internal fluid, the centre of the earth (A) being the origin, the line joining the centres of the earth and sun (A S) the axis of x, and the axis of z being perpendicular to the plane of the ecliptic. We shall then have

$$\text{the disturbing force on Q parallel to } x = 2\,\frac{\mu}{r_{\prime}^{3}}\cdot x$$

$$\text{the disturbing force on Q parallel to } y = -\,\frac{\mu}{r_{\prime}^{3}}\cdot y$$

$$\text{the disturbing force on Q parallel to } z = -\,\frac{\mu}{r_{\prime}^{3}}\cdot z,$$

substituting these quantities for X, Y, and Z respectively in the expression $X\,d\,x + Y\,d\,y + Z\,d\,z$, it manifestly becomes a perfect derivative. Consequently the condition of equilibrium is satisfied, and the action of the sun has no tendency to communicate motion to the internal fluid.

II. *Disturbing Force of the Moon.*—The investigation and result are precisely the same as for the sun.

III. *Centrifugal Force.*—In investigating the equations of motion for the solid shell, it has been assumed (Arts. 4. 5.) that the spheroidal axis of the shell will not generally be coincident with the axis A B′ of rotation, which is now proved to be true, since the disturbing forces of the sun and moon, while they produce a motion of the shell, cause no motion by their immediate action in the fluid. Let B′ A b' (fig. 2.) be the axis of rotation of the interior fluid, and suppose the spheroidal axis first to coincide with it, the dotted ellipse then representing the section of the interior surface of the solid shell. The shell, its form being supposed coincident with that of equilibrium of the fluid, will, in this case, produce no constraint on the fluid motion; but conceive the shell to be afterwards brought into the position represented by the continuous ellipse, A B being its spheroidal axis, while B′ b' shall still represent the instantaneous axis of rotation of the fluid. It is manifest that the planes of rotatory motion of the fluid par-

ticles near B′ and b' can no longer, as in the former case, be perpendicular to A B′, but must be constrained to move in planes very nearly parallel to the tangent planes at B′ and b'; and it is also sufficiently obvious that whatever effect is produced on the

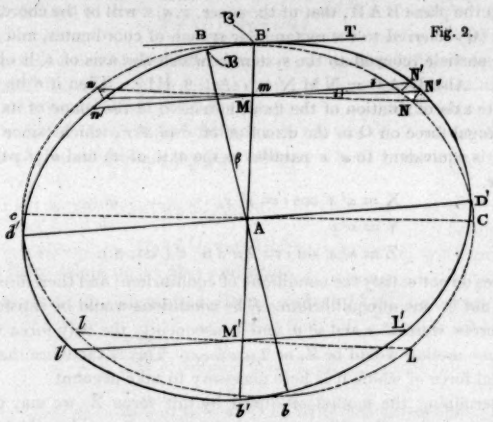

Fig. 2.

planes of motion of the above particles, a similar effect must be produced on those more remote from B′ and b'. Moreover, the mutual action of contiguous particles situated in contiguous planes of rotation will necessarily preserve a very approximate parallelism of these planes throughout the mass. We may conclude, therefore, that the instantaneous planes of rotation will always approximate, in a greater or less degree, to parallelism with the tangent planes at B′ and b', the extremities of the instantaneous axis of rotation of the fluid. In the investigations immediately following, we shall assume this to be accurately true, and shall prove subsequently the accuracy of the approximation to the true motions thus obtained. If M N′ be one of these planes of motion, M N perpendicular to A B′, and ι = angle N M N′, we shall have $\iota = 2\,\epsilon\,\beta$, as may be easily proved.

9. The sections of the interior surface of the shell made by these planes of rotatory motion will be similar ellipses, so that the angular velocity of rotation will no longer be accurately uniform. If, however, e' be the eccentricity of these sections, ϵ the ellipticity of the spheroid, and β the angle B A B′ (which will always be extremely small), it is easily shown that

$$e'^2 = 2\,\epsilon\,\beta.$$

This is so small that we shall still consider the angular velocity uniform, which will be proved in the sequel to be correct to the degree of approximation to which it is requisite to carry our investigations.

We may proceed to determine the centrifugal force on the fluid.

10. Let A B′ be now taken for the common axis of z and z', A C, perpendicular to A B′, for that of x, and A D′, conjugate to A B′, for that of x', the axis of y being perpendicular to the plane B A B′, that of the paper. x, y, z will be the coordinates of any fluid particle (Q) referred to the rectangular system of coordinates, and x', y, z' those of the same particle referred to the system in which the axis of z' is oblique to the plane of $x'\,y$. Also D′ A C = N M N′ = ι (Art. 8. III.). Then if r' be the distance of Q from the axis of rotation of the fluid, measured in the plane of its motion, the whole centrifugal force on Q in the direction of $r' = \omega^2 r'$, which (since x' and y are rectangular) is equivalent to $\omega^2 x'$ parallel to the axis of x', and $\omega^2 y'$ parallel to that of y. Hence

$$X = \omega^2 x' \cos \iota = \omega^2 x,$$
$$Y = \omega^2 y,$$
$$Z = \omega^2 x' \sin \iota = 2\,\omega^2 \varepsilon \beta \,.\, x \text{ (Art. 8.)}.$$

These forces do not satisfy the conditions of equilibrium, and therefore the assumed position will not be one of equilibrium. The conditions would be satisfied, however, if the only forces were $\omega^2 x$ and $\omega^2 y$, and consequently the only force which would tend to produce motion would be Z, or $2\,\omega^2 \varepsilon \beta \,.\, x$. This is therefore the only part of the centrifugal force of which it is here necessary to take account.

11. In determining the motion produced by this force Z, we may observe, that since it acts symmetrically with respect to the plane of $x\,z$, by which the interior surface of the shell is divided symmetrically, there can be no motion in directions perpendicular to that plane. The motion of each fluid particle must therefore be in a plane perpendicular to the axis of y, and must moreover be independent of y, since Z is so. Hence the determination of the motion is reduced to the case of fluid motion in one plane, where (the plane itself being taken for that of $x\,z$) each particle is acted on by the force $Z = 2\,\omega^2 \varepsilon \beta \,.\, x$, and the boundary of the fluid is an ellipse whose ellipticity is ε, and whose centre is the origin of coordinates.

12. The general equation

$$d\,p = X\,d\,x + Z\,d\,z,$$

where X and Z are forces which maintain the fluid in equilibrium, is easily reduced to

$$d\,p = R\,d\,r + \Theta\,r\,d\,\theta,$$

where r and θ are polar coordinates of any fluid particle, R the accelerating force upon it in the direction of r, and Θ that in a direction perpendicular to the former. Hence we have the condition of equilibrium

$$\frac{d\,R}{d\,\theta} = \frac{d\,.\,\Theta\,r}{d\,r};$$

or if Θ be the force acting on the fluid, but $\Theta + \Theta'$ that which would produce equilibrium with R, we have

$$\frac{d\,R}{d\,\theta} = \frac{d\,.\,(\Theta\,r + \Theta'\,r)}{d\,r}.$$

Now in the case to which this condition is to be applied, we have (θ being measured from the axis of x, and r from the origin of x and z)

$$\begin{aligned} R &= Z \sin\theta \\ &= 2\,\omega^2\,\varepsilon\,\beta\, r \cos\theta \sin\theta \\ &= \frac{k}{2}\, r \sin 2\,\theta, \qquad (k = 2\,\omega^2\,\varepsilon\,\beta)\,; \end{aligned}$$

$$\begin{aligned} \Theta\, r &= Z \cos\theta \,.\, r \\ &= k\, r^2 \cos^2\theta, \\ \therefore \frac{d\,R}{d\,\theta} &= k\, r \cos 2\,\theta, \\ \frac{d\,.\,\Theta\, r}{d\, r} &= 2\, k\, r \cos^2\theta \\ &= k\, r\,(1 + \cos 2\,\theta). \end{aligned}$$

Substituting these values in the above equation,

$$k\, r \cos 2\,\theta = k\, r\,(1 + \cos 2\,\theta) + \frac{d\,.\,\Theta' r}{d\, r},$$

$$\therefore \frac{d\,.\,\Theta' r}{d\, r} = -\, k\, r,$$

$$\Theta' r = -\frac{k}{2}\, r^2 + \Phi\,(\theta)\,;$$

and since $\Theta' r$ must vanish with r, $\Phi\,(\theta)$ must $= 0$, and

$$\Theta' = -\frac{k}{2}\, r\,;$$

or if forces $\Theta' = -\frac{k}{2}\, r$, and $Z = k\, x$ act on each fluid particle, there will be no motion.

Now suppose forces $\frac{k}{2}\, r$ and $-\frac{k}{2}\, r$ equal and in opposite directions to act on each particle perpendicular to r, together with Z. The motion produced by Z will not be affected by this superposition. But the forces Z $(= k\, x)$ and $-\frac{k}{2}\, r$ are in equilibrium, and therefore the motion produced by Z must be the same as that which would be produced by $\frac{k}{2}\, r$, acting perpendicular to r.

13. Since the motion we are considering is in space of two dimensions, the surface of the fluid must be defined by some plane curve, if the particular form of which the result at which we have just arrived is quite independent, being subject only to the condition that no part of the fluid surface shall be free. Let us suppose the curve to be a circle, of which the centre is the origin of coordinates. The angular accelerating force on each particle $= \frac{k}{2}$, and is, therefore, the same for every particle. Also the

reaction of the surface would, in this case, have no effect on the angular motion of the fluid. Consequently the angular velocity generated by Z in a unit of time would $= \frac{k}{2}$.

14. If the boundary of the fluid be an ellipse of which the centre is the origin and the eccentricity very small, the same result will manifestly be very approximately true.

This last is the case, in which it was necessary to determine the angular motion (Art. 11.). It follows that the angular velocity of the internal fluid mass round the axis of y, which would be generated by the force Z in a unit of time $= \frac{k}{2}$, or (substituting the proper value of k) it $= \omega^2 \varepsilon \beta$, neglecting quantities of the order $\varepsilon^2 \beta$.

15. This angular velocity will be compounded with that about the axis of z (ω). Now if we again suppose the fluid mass to be spherical, it would manifestly move precisely as if it were solid, since the angular velocities ω and $\omega^2 \varepsilon \beta$ about the axes of z and y respectively are common to all the particles of the mass, and the axis of instantaneous rotation would consequently have an angular motion in space perpendicular to the plane B A B′ (fig. 2.) and $= \frac{\alpha'}{\omega} = \omega \varepsilon \beta$. If the fluid mass be spheroidal, as in our actual case, the ellipticity being small the same result will be very approximately true.

We may now proceed to the formation of the differential equations for the motion of the instantaneous axis of rotation of the interior fluid, or of the point P′ (fig. 1.).

§. *Formation of the Differential Equations for the Motion of* P′ (fig. 1.).

16. Since the angular velocity of A B′ (fig. 2.) is $\omega \varepsilon . \beta$ (Art. 15.) in a direction perpendicular to the plane B A B′, the linear velocity of P′ (fig. 1.) will also be $\omega \varepsilon . \beta$, or $\omega \varepsilon$. P P′; or if $\omega \varepsilon = 2 \gamma_2$, the linear velocity of P′ perpendicular to P P′ $= 2 \gamma_2$. P P′. This is exactly similar to the expression for the motion of P perpendicular to P P′ (Art. 5. V.), but it will be observed that the angular motion of the fluid about the axis perpendicular to the plane B A B′ (fig. 2.) which the centrifugal force tends to produce, is in the direction opposite to that of the angular motion of the shell which the fluid pressure on its interior surface, arising from this centrifugal force, tends to produce (Art. 14.). Hence to obtain the differential equations for the motion of P′ we have only to put $-\gamma_2$ for γ_1 in the equations of Art. 5. V. We thus have (now denoting by $x\ y\ x'$ and y' the same quantities as in Art. 5.).

$$\left.\begin{aligned} \frac{dx'}{dt} - 2\gamma_2 (y - y') = 0 \\ \frac{dy'}{dt} + 2\gamma_2 (x - x') = 0 \end{aligned}\right\} \quad \text{(B.)}$$

§. *Integration of the Differential Equations for the Motions of* P *and* P′.

17. The equations (A) and (B) (Arts. 6, 16.) form a system of four simultaneous differential equations, viz.

$$\frac{dx}{dt} + 2\gamma_1 (y - y') = A - B\cos 2(nt + \lambda) - B'\cos 2(n't + \lambda'), \quad . \quad . \quad . \quad (1.)$$

$$\frac{dy}{dt} - 2\gamma_1 (x - x') = \quad D\sin 2(nt + \lambda) + D'\sin 2(n't + \lambda'), \quad . \quad . \quad . \quad (2.)$$

$$\frac{dx'}{dt} - 2\gamma_2 (y - y') = 0, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3.)$$

$$\frac{dy'}{dt} + 2\gamma_2 (x - x') = 0. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4.)$$

(1.) $\times\ \gamma_2 +$ (3.) $\times\ \gamma_1$ gives

$$\gamma_2 \frac{dx}{dt} + \gamma_1 \frac{dx'}{dt} = \gamma_2 A - \gamma_2 B\cos 2(nt + \lambda) - \gamma_2 B'\cos 2(n't + \lambda'),$$

and (2.) $\times\ \gamma_2 +$ (4.) $\times\ \gamma_1$ gives

$$\gamma_2 \frac{dy}{dt} + \gamma_1 \frac{dy'}{dt} = \gamma_2 D\sin 2(nt + \lambda) + \gamma_2 D'\sin 2(n't + \lambda').$$

Integrating these two last equations,

$$\gamma_2 x + \gamma_1 x' = \gamma_2 At - \frac{\gamma_2 B}{2n}\sin 2(nt + \lambda) - \frac{\gamma_2 B'}{2n'}\sin 2(n't + \lambda') + c_1, \quad . \quad . \quad (5.)$$

$$\gamma_2 y + \gamma_1 y' = -\frac{\gamma_2 D}{2n}\cos 2(nt + \lambda) - \frac{\gamma_2 D}{2n'}\cos 2(n't + \lambda') + c_2. \quad . \quad . \quad . \quad (6.)$$

To determine the arbitrary constants c_1 and c_2, let x, y, x' and y' each $= 0$ when $t = 0$. Then

$$c_1 = \frac{\gamma_2 B}{2n}\sin 2\lambda + \frac{\gamma_2 B'}{2n'}\sin 2\lambda',$$

$$c_2 = \frac{\gamma_2 D}{2n}\cos 2\lambda + \frac{\gamma_2 D'}{2n'}\cos 2\lambda'.$$

Equations (5.) and (6.) are two integrals of our four differential equations.

18. Substituting in (1.) and (2.) for y' and x', we obtain

$$\frac{dx}{dt} + 2(\gamma_1 + \gamma_2)\, y = 2c_2 + A - \left(B + \frac{\gamma_2 D}{n}\right)\cos 2(nt + \lambda)$$
$$- \left(B' + \frac{\gamma_2 D'}{n'}\right)\cos 2(n't + \lambda'),$$

$$\frac{dy}{dt} - 2(\gamma_1 + \gamma_2)\, x = -2c_1 + \left(D + \frac{\gamma_2 B}{n}\right)\sin 2(nt + \lambda)$$
$$+ \left(D' + \frac{\gamma_2 B'}{n'}\right)\sin 2(n't + \lambda') - 2\gamma_2 At.$$

Let $\qquad \gamma = \gamma_1 + \gamma_2, \qquad K = \gamma_2 A,$

$\qquad L = 2c_2 + A, \qquad L' = -2c_1,$

$$M = B + \frac{\gamma_2 D}{n}, \qquad M' = B' + \frac{\gamma_2 D'}{n'},$$

$$N = D + \frac{\gamma_2 B}{n}, \qquad N' = D' + \frac{\gamma_2 B'}{n'}.$$

Then

$$\frac{dx}{dt} + 2\gamma y = L - M\cos 2(nt + \lambda) - M'\cos 2(n't + \lambda'),$$

$$\frac{dy}{dt} - 2\gamma x = L' + N\sin 2(nt + \lambda) + N'\sin 2(n't + \lambda') - 2Kt.$$

The integration of these equations will be easily effected by the method of the variation of the arbitrary constants. The simultaneous equations

$$\frac{dx}{dt} + 2\gamma y = 0,$$

$$\frac{dy}{dt} - 2\gamma x = 0$$

are satisfied by

$$\left.\begin{aligned} x &= C_1\cos 2\gamma t - C_2\sin 2\gamma t \\ y &= C_1\sin 2\gamma t + C_2\cos 2\gamma t \end{aligned}\right\} \quad \text{(C.)}$$

and if we write equations (B.) under the form

$$\frac{dx}{dt} + 2\gamma y = \Phi(t),$$

$$\frac{dx}{dt} - 2\gamma x = \Psi(t),$$

we shall have, considering C_1 and C_2 as functions of t,

$$\frac{dC_1}{dt}\cos 2\gamma t - \frac{dC_2}{dt}\sin 2\gamma t = \Phi(t),$$

$$\frac{dC_1}{dt}\sin 2\gamma t + \frac{dC_2}{dt}\cos 2\gamma t = \Psi(t);$$

$$\therefore \frac{dC_1}{dt} = \cos 2\gamma t\,.\,\Phi(t) + \sin 2\gamma t\,.\,\Psi(t),$$

$$\frac{dC_2}{dt} = -\sin 2\gamma t\,.\,\Phi(t) + \cos 2\gamma t\,\Psi(t).$$

Each term in C_1 and C_2 corresponding to the several terms in $\Phi(t)$ and $\Psi(t)$ may be determined separately.

Let $\Phi(t) = L$, $\Psi(t) = L'$; then

$$\frac{dC_1}{dt} = L\,.\cos 2\gamma t + L'\sin 2\gamma t,$$

$$\frac{dC_2}{dt} = -L\sin 2\gamma t + L'\cos 2\gamma t;$$

$$\therefore C_1 = \frac{L}{2\gamma} \sin 2\gamma t - \frac{L'}{2\gamma} \cos 2\gamma t,$$

$$C_2 = \frac{L}{2\gamma} \cos 2\gamma t + \frac{L'}{2\gamma} \sin 2\gamma t.$$

Let $\Phi(t) = -M \cos 2(nt + \lambda)$,

$\Psi(t) = \quad N \sin 2(nt + \lambda)$; then

$$\frac{dC_1}{dt} = -M \cos 2\gamma t \,.\, \cos 2(nt + \lambda) + N \sin 2\gamma t \,.\, \sin 2(nt + \lambda),$$

$$\frac{dC_2}{dt} = \quad M \sin 2\gamma t \,.\, \cos 2(nt + \lambda) + N \cos 2\gamma t \,.\, \sin 2(nt + \lambda);$$

$$\therefore \frac{dC_1}{dt} = -\frac{M}{2}\left\{\cos 2(\overline{\gamma - n}\, t - \lambda) + \cos 2(\overline{\gamma + n}\, t + \lambda)\right\}$$

$$+ \frac{N}{2}\left\{\cos 2(\overline{\gamma - n}\, t - \lambda) - \cos 2(\overline{\gamma + n}\, t + \lambda)\right\};$$

and $\therefore C_1 = -\dfrac{M - N}{2} \cdot \dfrac{\sin 2(\overline{\gamma - n}\, t - \lambda)}{2(\gamma - n)} - \dfrac{M + N}{2} \dfrac{\sin 2(\overline{\gamma + n}\, t + \lambda)}{2(\gamma + n)}$;

$$\frac{dC_2}{dt} = \frac{M}{2}\left\{\sin 2(\overline{\gamma + n}\, t + \lambda) + \sin 2(\overline{\gamma - n}\, t - \lambda)\right\}$$

$$+ \frac{N}{2}\left\{\sin 2(\overline{\gamma + n}\, t + \lambda) - \sin 2(\overline{\gamma - n}\, t - \lambda)\right\};$$

and $\therefore C_2 = -\dfrac{M + N}{2} \cdot \dfrac{\cos 2(\overline{\gamma + n}\, t + \lambda)}{2(\gamma + n)} - \dfrac{M - N}{2} \cdot \dfrac{\cos 2(\overline{\gamma - n}\, t - \lambda)}{2(\gamma - n)}$.

Taking $\varphi(t) = -M' \cos 2(n' t + \lambda')$,

$\psi(t) = \quad N' \sin 2(n' t + \lambda')$,

we shall obtain in a similar manner

$$C_1 = -\frac{M' - N'}{2} \cdot \frac{\sin 2(\overline{\gamma - n'}\, t - \lambda')}{2(\gamma - n')} - \frac{M' + N'}{2} \cdot \frac{\sin 2(\overline{\gamma + n'}\, t + \lambda')}{2(\gamma + n')},$$

$$C_2 = -\frac{M' + N'}{2} \cdot \frac{\cos 2(\overline{\gamma + n'}\, t + \lambda')}{2(\gamma + n')} - \frac{M' - N'}{2} \cdot \frac{\cos 2(\overline{\gamma - n'}\, t - \lambda')}{2(\gamma - n')}.$$

Let $\varphi(t) = 0$, $\psi(t) = -2Kt$; then

$$\frac{dC_1}{dt} = -2Kt \,.\, \sin 2\gamma t,$$

$$\frac{dC_2}{dt} = -2Kt \,.\, \cos 2\gamma t;$$

$$\therefore C_1 = -2K\left(\frac{\sin 2\gamma t}{4\gamma^2} - \frac{\cos 2\gamma t}{2\gamma} \cdot t\right),$$

$$C_2 = -2K\left(\frac{\cos 2\gamma t}{4\gamma^2} + \frac{\sin 2\gamma t}{2\gamma} \cdot t\right).$$

Hence for the complete values of C_1 and C_2 we have

$$\begin{aligned}
C_1 = {} & \frac{L}{2\gamma}\sin 2\gamma t - \frac{L'}{2\gamma}\cos 2\gamma t \\
& - \frac{M-N}{4(\gamma-n)}\sin 2(\overline{\gamma-n}\,t-\lambda) - \frac{M+N}{4(\gamma+n)}\sin 2(\overline{\gamma+n}\,t+\lambda) \\
& - \frac{M'-N'}{4(\gamma-n')}\sin 2(\overline{\gamma-n'}\,t-\lambda') - \frac{M'+N'}{4(\gamma+n')}\sin 2(\overline{\gamma+n'}\,t+\lambda') \\
& - 2\,K\,.\left(\frac{\sin 2\gamma t}{4\gamma^2} - \frac{\cos 2\gamma t}{2\gamma}t\right) + c_3;
\end{aligned}$$

$$\begin{aligned}
C_2 = {} & \frac{L}{2\gamma}\cos 2\gamma t + \frac{L'}{2\gamma}\sin 2\gamma t \\
& - \frac{M+N}{4(\gamma+n)}\cos 2(\overline{\gamma+n}\,t+\lambda) - \frac{M-N}{4(\gamma-n)}\cos 2(\overline{\gamma-n}\,t-\lambda) \\
& - \frac{M'+N'}{4(\gamma+n')}\cos 2(\overline{\gamma+n'}\,t+\lambda') - \frac{M'-N'}{4(\gamma-n')}\cos 2(\overline{\gamma-n'}\,t-\lambda') \\
& - 2\,K\left(\frac{\cos 2\gamma t}{4\gamma^2} + \frac{\sin 2\gamma t}{2\gamma}\right) + c_4,
\end{aligned}$$

where c_3 and c_4 are arbitrary constants.

Substituting these values in equations (C.), we obtain after reduction,

$$\left.\begin{aligned}
x = {} & -\frac{L'}{2\gamma} + \frac{nM-\gamma N}{2(\gamma^2-n^2)}\sin 2(nt+\lambda) + \frac{n'M'-\gamma N'}{2(\gamma^2-n'^2)}\sin 2(n't+\lambda') \\
& + c_3\cos 2\gamma t - c_4\sin 2\gamma t + \frac{K}{\gamma}\cdot t; \qquad (7.) \\
y = {} & \frac{L}{2\gamma} - \frac{K}{2\gamma^2} - \frac{\gamma M-nN}{2(\gamma^2-n^2)}\cos 2(nt+\lambda) - \frac{\gamma M'-n'N'}{2(\gamma^2-n'^2)}\cos 2(n't+\lambda') \\
& + c_3\sin 2\gamma t + c_4\cos 2\gamma t. \qquad (8.)
\end{aligned}\right\}\ (D.)$$

To determine the arbitrary constants c_3 and c_4, we have $x = 0$ and $y = 0$ when $t = 0$, which gives

$$c_3 = -\frac{nM-\gamma N}{2(\gamma^2-n^2)}\sin 2\lambda - \frac{n'M'-\gamma N'}{2(\gamma^2-n'^2)}\sin 2\lambda' + \frac{L'}{2\gamma},$$

$$c_4 = \frac{\gamma M-nN}{2(\gamma^2-n^2)}\cos 2\lambda + \frac{\gamma M'-n'N'}{2(\gamma^2-n'^2)}\cos 2\lambda' - \left(\frac{L}{2\gamma} - \frac{K}{2\gamma^2}\right).$$

Equations (5) (6) (7) and (8) are the four integrals of our four differential equations.

We have now to express the coefficients of equations (D.) in terms of A, B, B′, D, and D′.

$$-\frac{L'}{2\gamma} = \frac{\gamma_2}{\gamma}\left(\frac{B}{2n}\sin 2\lambda + \frac{B'}{2n'}\sin 2\lambda'\right);$$

$$\frac{L}{2\gamma} - \frac{K}{2\gamma^2} = \frac{\gamma_2}{\gamma}\left(\frac{D}{2n}\cos 2\lambda + \frac{D'}{2n'}\cos 2\lambda'\right) + \frac{1}{\gamma}\frac{A}{2} - \frac{\gamma_2}{\gamma^2}\frac{A}{2}$$

$$= \frac{\gamma_2}{\gamma}\left(\frac{D}{2n}\cos 2\lambda + \frac{D'}{2n'}\cos 2\lambda'\right) + \frac{\gamma_1}{\gamma^2}\cdot\frac{A}{2}.$$

$$n\,M - \gamma\,N = n\,B - \gamma_2\,D - \gamma\,D - \gamma\frac{\gamma_2}{n}B$$

$$= \left\{-\frac{\gamma^2 - n^2}{n}\frac{B}{D} + \gamma_1\left(\frac{\gamma}{n}\frac{B}{D} - 1\right)\right\}D;$$

$$\therefore \frac{n\,M - \gamma\,N}{2(\gamma^2 - n^2)} = \left\{-\frac{1}{n}\frac{B}{D} + \frac{\gamma_1}{\gamma^2 - n^2}\left(\frac{\gamma}{n}\frac{B}{D} - 1\right)\right\}\frac{D}{2}.$$

Similarly,

$$\frac{n'\,M' - \gamma\,N'}{2(\gamma^2 - n'^2)} = \left\{-\frac{1}{n'}\frac{B'}{D'} + \frac{\gamma_1}{\gamma^2 - n'^2}\left(\frac{\gamma}{n'}\frac{B'}{D'} - 1\right)\right\}\frac{D'}{2}.$$

$$\gamma\,M - n\,N = \gamma\,B + \gamma\frac{\gamma_2}{n}D - n\,D - \gamma_2\,B$$

$$= \left\{\frac{\gamma^2 - n^2}{n} - \gamma_1\left(\frac{\gamma}{n} - \frac{B}{D}\right)\right\}D;$$

$$\therefore -\frac{\gamma\,M - n\,N}{2(\gamma^2 - n^2)} = -\left\{\frac{1}{n} - \frac{\gamma_1}{\gamma^2 - n^2}\left(\frac{\gamma}{n} - \frac{B}{D}\right)\right\}\frac{D}{2}.$$

Similarly,

$$-\frac{\gamma\,M' - n'\,N'}{2(\gamma^2 - n'^2)} = -\left\{\frac{1}{n'} - \frac{\gamma_1}{\gamma^2 - n'^2}\left(\frac{\gamma}{n'} - \frac{B'}{D'}\right)\right\}\frac{D'}{2}.$$

$$\frac{K}{\gamma} = \frac{\gamma_2}{\gamma}\cdot A.$$

$$c_3 = \left\{\frac{\gamma_1}{\gamma}\frac{B}{D}\frac{1}{n} - \frac{\gamma_1}{\gamma^2 - n^2}\left(\frac{\gamma}{n}\frac{B}{D} - 1\right)\right\}\frac{D}{2}\sin 2\lambda$$

$$+ \left\{\frac{\gamma_1}{\gamma}\cdot\frac{B'}{D'}\frac{1}{n'} - \frac{\gamma_1}{\gamma^2 - n'^2}\left(\frac{\gamma}{n'}\frac{B}{D} - 1\right)\right\}\frac{D'}{2}\sin 2\lambda';$$

$$c_4 = \left\{\frac{\gamma_1}{\gamma}\frac{1}{n} - \frac{\gamma_1}{\gamma^2 - n^2}\left(\frac{\gamma}{n} - \frac{B}{D}\right)\right\}\frac{D}{2}\cos 2\lambda$$

$$+ \left\{\frac{\gamma_1}{\gamma}\frac{1}{n'} - \frac{\gamma_1}{\gamma^2 - n'^2}\left(\frac{\gamma}{n'} - \frac{B'}{D'}\right)\right\}\frac{D'}{2}\cos 2\lambda' - \frac{\gamma_1}{\gamma^2}\frac{A}{2}.$$

Hence we obtain by substitution,

$$\left.\begin{aligned} x = &\left\{-\frac{B}{2n} + \frac{\gamma_1}{\gamma^2 - n^2}\left(\frac{\gamma}{n}\frac{B}{D} - 1\right)\frac{D}{2}\right\}\sin 2(n\,t + \lambda) \\ &+ \left\{-\frac{B'}{2n'} + \frac{\gamma_1}{\gamma^2 - n'^2}\left(\frac{\gamma}{n'}\frac{B'}{D'} - 1\right)\frac{D'}{2}\right\}\sin 2(n'\,t + \lambda') \\ &+ \left[\begin{aligned} &\frac{\gamma_1}{\gamma}\cdot\frac{B}{2n}\sin 2\lambda - \frac{\gamma_1}{\gamma^2 - n^2}\left(\frac{\gamma}{n}\frac{B}{D} - 1\right)\frac{D}{2}\sin 2\lambda \\ &+ \frac{\gamma_1}{\gamma}\cdot\frac{B'}{2n'}\sin 2\lambda' - \frac{\gamma_1}{\gamma^2 - n'^2}\left(\frac{\gamma}{n'}\frac{B'}{D'} - 1\right)\frac{D'}{2}\sin 2\lambda' \end{aligned}\right]\cos 2\gamma\,t \end{aligned}\right\} \quad \text{(E.)}$$

$$
\begin{aligned}
&- \left\{ \begin{array}{l} \frac{\gamma_1}{\gamma} \cdot \frac{D}{2n} \cdot \cos 2\lambda - \frac{\gamma_1}{\gamma^2 - n^2} \left(\frac{\gamma}{n} - \frac{B}{D} \right) \frac{D}{2} \cos 2\lambda \\ + \frac{\gamma_1}{\gamma} \cdot \frac{D'}{2n'} \cos 2\lambda' - \frac{\gamma_1}{\gamma^2 - n'^2} \left(\frac{\gamma}{n'} - \frac{B'}{D'} \right) \frac{D'}{2} \cos 2\lambda' - \frac{\gamma_1}{\gamma^2} \frac{A}{2} \end{array} \right\} \sin 2\gamma t \\
&+ \frac{\gamma_2}{\gamma} A t + \frac{\gamma_2}{\gamma} \left(\frac{B}{2n} \sin 2\lambda + \frac{B'}{2n'} \sin 2\lambda' \right); \\
y = &- \left\{ \frac{D}{2n} - \frac{\gamma_1}{\gamma^2 - n^2} \left(\frac{\gamma}{n} - \frac{B}{D} \right) \frac{D}{2} \right\} \cos 2(nt + \lambda) \\
&- \left\{ \frac{D'}{2n'} - \frac{\gamma_1}{\gamma^2 - n'^2} \left(\frac{\gamma}{n'} - \frac{B'}{D'} \right) \frac{D'}{2} \right\} \cos 2(n't + \lambda') \\
&+ \left\{ \begin{array}{l} \frac{\gamma_1}{\gamma} \frac{B}{2n} \sin 2\lambda - \frac{\gamma_1}{\gamma^2 - n^2} \left(\frac{\gamma}{n} \frac{B}{D} - 1 \right) \frac{D}{2} \sin 2\lambda \\ + \frac{\gamma_1}{\gamma} \frac{B'}{2n'} \sin 2\lambda' - \frac{\gamma_1}{\gamma^2 - n'^2} \left(\frac{\gamma}{n'} \frac{B'}{D'} - 1 \right) \frac{D'}{2} \sin 2\lambda' \end{array} \right\} \sin 2\gamma t \qquad \text{(F.)} \\
&+ \left\{ \begin{array}{l} \frac{\gamma_1}{\gamma} \frac{D}{2n} \cos 2\lambda - \frac{\gamma_1}{\gamma^2 - n^2} \left(\frac{\gamma}{n} - \frac{B}{D} \right) \frac{D}{2} \cos 2\lambda \\ + \frac{\gamma_1}{\gamma} \frac{D'}{2n'} \cos 2\lambda' - \frac{\gamma_1}{\gamma^2 - n'^2} \left(\frac{\gamma}{n'} - \frac{B'}{D'} \right) \frac{D'}{2} \cos 2\lambda' - \frac{\gamma_1}{\gamma^2} \cdot \frac{A}{2} \end{array} \right\} \cos 2\gamma t \\
&+ \frac{\gamma_2}{\gamma} \left(\frac{D}{2n} \cos 2\lambda + \frac{D'}{2n'} \cos 2\lambda' \right) + \frac{\gamma_1}{\gamma^2} \cdot \frac{A}{2}.
\end{aligned}
$$

From equations (5.) and (6.) we have

$$
\begin{aligned}
x' &= - \frac{\gamma_2}{\gamma_1} \frac{B}{2n} \sin 2(nt + \lambda) - \frac{\gamma_2}{\gamma_1} \frac{D'}{2n'} \sin 2(n't + \lambda') + \frac{\gamma_2}{\gamma_1} A t + \frac{c_1}{\gamma_1} - \frac{\gamma_2}{\gamma_1} x, \\
y' &= - \frac{\gamma_2}{\gamma_1} \frac{D}{2n} \cos 2(nt + \lambda) - \frac{\gamma_2}{\gamma_1} \frac{D'}{2n'} \cos 2(n't + \lambda') + \frac{c_2}{\gamma_1} - \frac{\gamma_2}{\gamma_1} y;
\end{aligned}
$$

and substituting in these expressions the above values of x and y, we have

$$
\begin{aligned}
x' = &- \frac{\gamma_2}{\gamma^2 - n^2} \left(\frac{\gamma}{n} \frac{B}{D} - 1 \right) \frac{D}{2} \sin 2(nt + \lambda) \\
&- \frac{\gamma_2}{\gamma^2 - n'^2} \left(\frac{\gamma}{n'} \frac{B'}{D'} - 1 \right) \frac{D'}{2} \sin 2(n't + \lambda') \\
&- \left\{ \begin{array}{l} \frac{\gamma_2}{\gamma} \frac{B}{2n} \sin 2\lambda - \frac{\gamma_2}{\gamma^2 - n^2} \left(\frac{\gamma}{n} \frac{B}{D} - 1 \right) \frac{D}{2} \sin 2\lambda \\ + \frac{\gamma_2}{\gamma} \frac{B'}{2n'} \sin 2\lambda' - \frac{\gamma_2}{\gamma^2 - n'^2} \left(\frac{\gamma}{n'} \cdot \frac{B'}{D'} - 1 \right) \frac{D'}{2} \sin 2\lambda' \end{array} \right\} \cos 2\gamma t \qquad \text{(G.)} \\
&+ \left\{ \begin{array}{l} \frac{\gamma_2}{\gamma} \frac{D}{2n} \cos 2\lambda - \frac{\gamma_2}{\gamma^2 - n^2} \left(\frac{\gamma}{n} - \frac{B}{D} \right) \frac{D}{2} \cos 2\lambda \\ + \frac{\gamma^2}{\gamma} \frac{D'}{2n'} \cos 2\lambda' - \frac{\gamma_2}{\gamma^2 - n'^2} \left(\frac{\gamma}{n'} - \frac{B'}{D'} \right) \frac{D'}{2} \cos 2\lambda' - \frac{\gamma_2}{\gamma^2} \frac{A}{2} \end{array} \right\} \sin 2\gamma t \\
&+ \frac{\gamma_2}{\gamma} A t + \frac{\gamma_2}{\gamma} \left(\frac{B}{2n} \sin 2\lambda + \frac{B'}{2n'} \sin 2\lambda' \right);
\end{aligned}
$$

$$
\begin{aligned}
y' = & -\frac{\gamma_2}{\gamma^2 - n^2}\left(\frac{\gamma}{n} - \frac{B}{D}\right)\frac{D}{2}\cos 2\,(n\,t + \lambda) \\
& -\frac{\gamma_2}{\gamma^2 - n'^2}\left(\frac{\gamma}{n'} - \frac{B'}{D'}\right)\frac{D'}{2}\cos 2\,(n'\,t + \lambda') \\
& -\left\{\begin{array}{l} \frac{\gamma_2}{\gamma}\frac{B}{2\,n}\sin 2\,\lambda - \frac{\gamma_2}{\gamma^2 - n^2}\left(\frac{\gamma}{n}\frac{B}{D} - 1\right)\frac{D}{2}\sin 2\,\lambda \\ + \frac{\gamma_2}{\gamma}\frac{B'}{2\,n'}\sin 2\,\lambda' - \frac{\gamma_2}{\gamma^2 - n'^2}\left(\frac{\gamma}{n'}\frac{B'}{D'} - 1\right)\frac{D'}{2}\sin 2\,\lambda' \end{array}\right\}\sin 2\,\gamma\,t \qquad \text{(H.)} \\
& -\left\{\begin{array}{l} \frac{\gamma_2}{\gamma}\frac{D}{2\,n}\cos 2\,\lambda - \frac{\gamma_2}{\gamma^2 - n^2}\left(\frac{\gamma}{n} - \frac{B}{D}\right)\frac{D}{2}\cos 2\,\lambda \\ + \frac{\gamma_2}{\gamma}\frac{D'}{2\,n'}\cos 2\,\lambda' - \frac{\gamma_2}{\gamma^2 - n'^2}\left(\frac{\gamma}{n'} - \frac{B'}{D'}\right)\frac{D'}{2}\cos 2\,\lambda' - \frac{\gamma_2}{\gamma^2}\frac{A}{2} \end{array}\right\}\cos 2\,\gamma\,t \\
& + \frac{\gamma_2}{\gamma}\left(\frac{D}{2\,n}\cos 2\,\lambda + \frac{D'}{2\,n'}\cos 2\,\lambda'\right) - \frac{\gamma_2}{\gamma^2}\frac{A}{2}.
\end{aligned}
$$

We have now to determine the values of A, B, D, B′, D′, γ_1 and γ_2, for which purpose (Art. 6.) we must find the values of the following quantities:

$$
\begin{array}{l}
A_1\ B_1\ D_1 \\
A_2\ B_2\ D_2 \\
A_3\ B_3\ D_3 \\
A_4\ B_4\ D_4 \\
\gamma_1\ \gamma_2.
\end{array}
$$

§. *Determination of the Numerical Values of the Constants in equations* (E), (F), (G) *and* (H).

19. *Values of* A_1, B_1, *and* D_1.—The moment of the disturbing force of the sun communicating a rotatory motion to the earth considered as a homogeneous spheroid,

$$
\begin{aligned}
&= \frac{3\,\mu}{2\,r_1^3}\cdot\frac{4\,\pi}{15}\,a_1^2\,c_1\,(a_1^2 - c_1^2)\sin 2\,\Delta \qquad \text{(Art. 1.)} \\
&= \frac{3\,\mu}{r_1^3}\cdot\frac{4\,\pi}{15}\,a_1^5\,\varepsilon\sin 2\,\Delta;
\end{aligned}
$$

and the moment of the forces on the shell

$$
\begin{aligned}
&= \frac{3\,\mu}{r_1^3}\cdot\frac{4\,\pi}{15}\,\varepsilon\,(a_1^5 - a^5)\sin 2\,\Delta \\
&= \frac{3\,\mu}{r_1^3}\cdot\frac{4\,\pi}{15}\,\varepsilon\,a^5\,(q^5 - 1)\sin 2\,\Delta,
\end{aligned}
$$

where $q = \frac{a_1}{a}$, the ratio of the outer to the inner radius of the shell.

The moment of inertia of the shell

$$= \frac{8\,\pi}{15}\,a^5\,(q^5 - 1),$$

and therefore

$$\frac{\alpha}{\omega} = \frac{3}{2}\frac{\mu}{r_1^3\omega}\,\varepsilon \sin 2\,\Delta$$

$$= \frac{6\pi^2}{T^2\omega}\,\varepsilon \sin 2\,\Delta \qquad (T = \text{one year})$$

$$= \frac{3\pi}{\nu T}\,\varepsilon \sin 2\,\Delta$$

(since $T\omega = 2\pi\nu$, $\nu = 366{\cdot}26$), which is the same as if the spheroid were entirely solid. This gives us*

$$A_1 = \frac{3\pi}{\nu}\,\varepsilon \sin I \cos I\,\frac{1}{T},$$

$$B_1 = \frac{3\pi}{\nu}\,\varepsilon \sin I \cos I\,\frac{1}{T},$$

$$D_1 = \frac{3\pi}{\nu}\,\varepsilon \sin I\,\frac{1}{T},$$

where I = inclination of the ecliptic.

20. *Values of* A_2, B_2, *and* D_2.—In a similar manner we obtain

$$A_2 = \frac{3\pi}{\nu'(\sigma+1)}\,\varepsilon \sin I \cos I \cos^2 i\,\frac{1}{T'},$$

$$B_2 = \frac{3\pi}{2\nu'(\sigma+1)}\,\varepsilon \cos 2\,I \sin 2\,I\,\frac{1}{T'},$$

$$D_2 = -\frac{3\pi}{2\nu'(\sigma+1)}\,\varepsilon \cos I \sin 2\,i\,\frac{1}{T'},$$

where i = inclination of the plane of the moon's orbit to that of the ecliptic; T' = moon's sidereal period, ν' = number of days in it = 27·32; and

$$\sigma = \frac{\text{mass of the moon}}{\text{mass of the earth}} = 70 \text{ nearly.}$$

21. *Numerical value of* A_3 B_3 and D_3.—Let the interior surface of the shell be referred to three rectangular co-ordinates $x\,y\,z$, the spheroidal axis being now that of z; and let p denote the normal pressure at the point $x\,y\,z$; ξ and ζ the angles which the normal makes with lines parallel to the axes of x and z respectively. Then if

$$X = p\,.\,\delta S \cos\xi, \qquad Z = p\,.\,\delta S \cos\zeta,$$

the moment of the normal pressures with respect to the axis of y

$$= \Sigma\,(Z\,x - X\,z)$$

$$= \Sigma\,(x\cos\zeta - z\cos\xi)\,p\,.\,\delta S$$

$$= \Sigma\left(x - z\frac{\cos\xi}{\cos\zeta}\right)p\,\delta S \cos\zeta.$$

But

$$\cos\zeta = \frac{1}{\sqrt{1 + \left(\frac{dx}{dx}\right)^2 + \left(\frac{dz}{dy}\right)^2}},$$

* Airy's Tracts, p. 210.

$$\cos\xi = \frac{-\frac{dz}{dx}}{\sqrt{1+\left(\frac{dz}{dx}\right)^2+\left(\frac{dz}{dy}\right)^2}}.$$

And in the spheroid

$$\frac{x^2+y^2}{a^2}+\frac{z^2}{c^2}=1,$$

$$\therefore -\frac{dz}{dx}=\frac{c^2}{a^2}\cdot\frac{x}{z};$$

whence by substitution, the moment about the axis of y

$$=\Sigma\left(1-\frac{c^2}{a^2}\right)xp\,.\,\delta S\cos\zeta$$

$$=2\,\varepsilon\,\Sigma\,xp\,.\,\delta S\cos\zeta,$$

where

$$\varepsilon=\frac{a-c}{a}.$$

In the determination of p it will suffice to consider the spheroidal surface as spherical; and since the disturbing force of the sun is the only force producing the rotation we are now considering, the other forces may be here neglected. Hence if the line joining the centres of the sun and earth be taken for the axis of x', and the plane through this line and the spheroidal axis for that of $x'\,z'$,

$$X=\frac{\mu}{r_1^3}\cdot 2\,x',$$

$$Y=-\frac{\mu}{r_1^3}\cdot y',$$

$$Z=-\frac{\mu}{r_1^3}\cdot z';$$

and

$$p=\frac{\mu}{r_1^3}\left\{2\,x'\,\delta\,x'-y'\,\delta\,y'-z'\,\delta\,z'\right\};$$

$$\therefore p=\frac{\mu}{r_1^3}\left\{x'^2-\frac{1}{2}\,(y'^2+z'^2)+C\right\}.$$

But considering the spheroid as approximately a sphere, and $x'\,y'\,z'$ a point on its surface,

$$y'^2+z'^2=a^2-x'^2,$$

$$\therefore p=\frac{1}{2}\cdot\frac{\mu}{r_1^3}\,(3\,x'^2-a^2+C);$$

and if the plane of $x\,z$ coincide with that of $x'\,z'$

$$x'=x\sin\Delta+z\cos\Delta,$$

Δ being the sun's north polar distance, and the spheroidal axis that of z.

$$\therefore p=\frac{3}{2}\cdot\frac{\mu}{r_1^3}\left\{x^2\sin^2\Delta+x\,z\sin 2\,\Delta+z^2\cos^2\Delta-\frac{a^2-C}{3}\right\};$$

and the moment about the axis of y

$$= 3\frac{\mu}{r_1^3}\,\varepsilon \iint \left\{ x^3 \sin^2\Delta + x^2 z \sin 2\Delta + z^2 x \cos^2\Delta - \frac{a^2 - C}{S}\, x \right\} \delta S \cos\zeta.$$

Let

$$z = r\cos\theta,$$
$$y = r\sin\theta\sin\varphi,$$
$$x = r\sin\theta\cos\varphi,$$

θ being the angle which r makes with the axis of z, and φ that which the plane of θ makes with that of $x\,z$. Considering the spheroid to be approximately a sphere we may put $r = a$, and $\zeta = \theta$. Also we shall have

$$\delta S = a^2 \sin\theta \,.\, \delta\theta\,\delta\varphi.$$

Hence

$$\iint x^3 \cos\zeta \,.\, \delta S = a^5 \iint \sin^4\theta \cos\theta \cos^3\varphi \, d\theta\, d\varphi,$$

$$\iint z^2 x \cos\zeta \,.\, \delta S = a^5 \iint \sin^2\theta \cos^3\theta \cos\varphi \, d\theta\, d\varphi,$$

$$\iint x \cos\zeta \,.\, \delta S = a^3 \iint \sin^2\theta \cos\theta \cos\varphi \, d\theta\, d\varphi,$$

$$\iint x^2 z \cos\zeta \,.\, \delta S = a^5 \iint \sin^2\theta \cos^2\theta \cos^2\varphi \, d\theta\, d\varphi.$$

Since $\int_0^{2\pi} \cos^{2n+1}\varphi \,.\, d\varphi = 0$, each of these integrals except the last will vanish between the limits $\varphi = 0$ and $\varphi = 2\pi$. Consequently the moment about the axis of y

$$= 3\frac{\mu}{r_1^3}\,\varepsilon \sin 2\Delta\, a^5 \iint \sin^3\theta \cos^2\theta \cos^2\varphi \, d\theta\, d\varphi \quad \left\{ \begin{array}{l} \varphi = 0 \text{ to } \varphi = 2\pi \\ \theta = 0 \text{ to } \theta = \pi \end{array} \right\}$$

$$= \frac{4\pi}{5}\frac{\mu}{r_1^3}\,\varepsilon \sin 2\Delta\, a^5.$$

The moment of inertia of the shell $= \frac{8\pi}{15} a^5 (q^5 - 1)$. Consequently the accelerating force of rotation arising from the pressure we are now considering

$$= \frac{3}{2}\frac{\mu}{r_1^3}\frac{\varepsilon}{q^5 - 1} \sin 2\Delta;$$

or if α' be the angular velocity generated by this force in a unit of time

$$\frac{\alpha'}{\omega} = \frac{3}{2} \cdot \frac{\mu}{r_1^3 \omega}\,\varepsilon \frac{1}{q^5 - 1} \sin 2\Delta,$$

$$= \frac{1}{q^5 - 1} \cdot \frac{\alpha}{\omega}. \qquad \text{(Art. 19.)}$$

Hence we have

$$A_3 = \frac{A_1}{q^5 - 1},$$

$$B_3 = \frac{B_1}{q^5 - 1},$$

$$D_3 = \frac{D_1}{q^5 - 1}.$$

22. *Values of* A_4, B_4, *and* D_4.—In the same manner we obtain

$$A_4 = \frac{A_2}{q^3 - 1},$$

$$B_4 = \frac{B_2}{q^3 - 1},$$

$$D_4 = \frac{D_2}{q^3 - 1}.$$

23. *Value of* γ_1.—We have seen (Art. 5. V.) that the angular motion of the solid shell produced by the centrifugal force of the fluid will be about an axis through the centre of the spheroid, and perpendicular to the plane passing through the spheroidal axis of the shell and the axis of rotation of the fluid. Let this axis be now taken for that of y', and the axis of rotation of the fluid for that of z', and let $x'\ y'\ z'$ be the co-ordinate of any particle of the fluid; then p denoting the fluid pressure there,

$$dp = \left(X' - \frac{d^2 x'}{dt^2}\right) dx' + \left(Y' - \frac{d^2 y'}{dt^2}\right) dy' + \left(Z' - \frac{d^2 z'}{dt^2}\right) dz'.$$

Now the impressed forces with which we are here concerned being those only which arise from centrifugal force on the fluid, we have (referring to Art. 12, and observing that the letters which are there unaccented are accented in our present notation)

$$X' = \omega^2 x', \quad Y' = \omega^2 y', \quad Z' = 2\,\omega^2\,\epsilon\,\beta\,.\,x'.$$

Also, since the motion of the fluid about the axis of y' is that produced by the accelerating force $\omega^2\,\epsilon\,\beta\,.\,r$ acting perpendicularly to r (Art. 12.), we have

$$\frac{d^2 x'}{dt^2} = -\,\omega^2\,\epsilon\,\beta\,.\,z', \qquad \frac{d^2 y'}{dt^2} = 0, \qquad \frac{d^2 z'}{dt^2} = \omega^2\,\epsilon\,\beta\,.\,x'.$$

Hence we have by substitution,

$$dp = \omega^2\,(x'\,dx' + y'\,dy') + \omega^2\,\epsilon\,\beta\,(z'\,dx' + x'\,dz'),$$

$$\therefore p = \frac{\omega^2}{2}\,(x'^2 + y'^2) + 2\,\epsilon\,\beta\,x'\,z' + C.$$

The moment of this force about the axis of y'

$$= 2\,\epsilon\,\Sigma\,x\,p\,.\,\delta\,S\cos\zeta, \qquad \text{(Art. 21.)}$$

$$= \omega^2\,\epsilon\,\Sigma\,x\,(x'^2 + y'^2 + 2\,\epsilon\,\beta\,x'\,z' + C)\,\delta\,S\cos\zeta.$$

In this expression we may consider $x'\ y'\ z'$ as co-ordinates of a point in the surface of a sphere, whose radius $= a$. Therefore

$$x'^2 + y'^2 = a^2 - z'^2 \text{ approximately.}$$

Also, since in our results we shall only retain terms of the order $\epsilon\,\beta$, the term $2\,\epsilon\,\beta\,x'\,z'$ may be neglected, the whole quantity under the integral sign being multiplied by ϵ. This is the term arising from the effective force on the fluid.

Hence, the moment about the axis of y

$$= \omega^2\,\epsilon\,\Sigma\,x\,(a^2 + C - z'^2)\,\delta\,S\cos\zeta.$$

The spheroidal axis being the axis of z we have

$$z' = z \cos\beta - x \sin\beta,$$

$$z'^2 = z^2 \cos^2\beta - z\,x \sin 2\beta + x^2 \sin^2\beta;$$

and substituting the expressions for x and z in terms of the polar co-ordinates as in article 21, the above expression reduces itself as in that article to

$$\omega^2 \varepsilon \sin 2\beta\, \Sigma\, z\, x^2\, \delta\, \mathrm{S} \cos\zeta$$

$$= \omega^2 \varepsilon \sin 2\beta\, a^5 \iint \sin^3\theta \cos^2\theta \cos^2\varphi\, d\theta\, d\varphi$$

$$= \frac{4\pi}{15}\, \omega^2 \varepsilon \sin 2\beta\, a^5.$$

Dividing this by the moment of inertia $\left(=\frac{8\pi}{15}\, a^5 (q^5 - 1)\right)$ we have (if α'' be the angular velocity generated in a unit of time by the force we are now considering)

$$\alpha'' = \frac{\omega^2 \varepsilon}{2(q^5 - 1)} \sin 2\beta,$$

and

$$\frac{\alpha''}{\omega} = \frac{\omega \varepsilon}{2(q^5 - 1)} \sin 2\beta;$$

and therefore (Art. 5, V.)

$$\gamma_1 = \frac{\omega \varepsilon}{2(q^5 - 1)}$$

$$= \frac{\pi \varepsilon}{q^5 - 1} \frac{1}{t_1},$$

since if t_1 = one day, $\omega = \frac{2\pi}{t_1}$.

24. *Value of* γ_2.—We have seen (Art. 16.) that

$$\gamma_2 = \frac{\omega \varepsilon}{2}$$

$$= \pi \varepsilon \,.\, \frac{1}{t_1}.$$

25. Substituting the values of A, B, B′, D, and D′ (Art. 6.) we obtain

$$\mathrm{A} = \frac{q^5}{q^5 - 1} \cdot \frac{3\pi}{\nu} \varepsilon \sin \mathrm{I} \cos \mathrm{I} \left(\frac{1}{\mathrm{T}} + \frac{1}{\sigma + 1} \frac{\nu}{\nu'} \cos^2 i \frac{1}{\mathrm{T}'}\right),$$

$$\mathrm{B} = \frac{q^5}{q^5 - 1} \cdot \frac{3\pi}{\nu} \varepsilon \sin \mathrm{I} \cos \mathrm{I} \frac{1}{\mathrm{T}},$$

$$\mathrm{B}' = \frac{q^5}{q^5 - 1} \cdot \frac{3\pi}{2\nu'(\sigma + 1)} \varepsilon \cos 2\,\mathrm{I} \sin 2 i \frac{1}{\mathrm{T}'},$$

$$\mathrm{D} = \frac{q^5}{q^5 - 1} \cdot \frac{3\pi}{\nu} \varepsilon \sin \mathrm{I} \frac{1}{\mathrm{T}},$$

$$\mathrm{D}' = -\frac{q^5}{q^5 - 1} \cdot \frac{3\pi}{2\nu'(\sigma + 1)} \varepsilon \cos \mathrm{I} \sin 2 i \frac{1}{\mathrm{T}'}.$$

These give us

$$\frac{B}{D} = \cos I,$$

$$\frac{B'}{D'} = -\frac{\cos 2 I}{\cos I},$$

$$n = \frac{2\pi}{T}, \quad n' = \frac{\pi}{\tau}, \qquad \text{(Art. 5, I. and II.)}$$

$$\gamma_1 = \frac{\pi \epsilon}{q^5 - 1} \frac{1}{t_1}, \qquad \text{(Art. 23.)}$$

$$\gamma_2 = \pi \epsilon \frac{1}{t_1}, \qquad \text{(Art. 24.)}$$

$$\therefore \gamma = \gamma_1 + \gamma_2 = \frac{q^5}{q^5 - 1} \pi \epsilon \frac{1}{t_1}.$$

For the convenience of reference we may also put down the following ratios:

$$\frac{n}{\gamma} = 2 \frac{q^5 - 1}{q^5} \cdot \frac{t_1}{\epsilon T} = 2 \frac{q^5 - 1}{q^5} \cdot \frac{1}{\nu \epsilon}, \qquad \left(\text{since } \frac{T}{t_1} = \nu\right)$$

$$\frac{n'}{\gamma} = \frac{q^5 - 1}{q^5} \cdot \frac{t_1}{\epsilon} = \frac{q^5 - 1}{q^5} \cdot \frac{T}{\tau} \cdot \frac{1}{\nu \epsilon},$$

$$\frac{\gamma_1}{\gamma} = \frac{1}{q^5}, \qquad \frac{\gamma_2}{\gamma} = \frac{q^5 - 1}{q^5},$$

$$\frac{\gamma_1}{\gamma^2} = \frac{1}{q^5} \cdot \frac{q^5 - 1}{q^5} \cdot \frac{t_1}{\pi \epsilon},$$

$$\nu = 366{\cdot}26, \qquad \frac{\tau}{T} = 18{\cdot}6,$$

$$\nu' = 27{\cdot}32, \qquad \sigma = 70.$$

Also, taking the ellipticity which the earth would have had if it had been originally fluid and homogeneous, we have $\epsilon = {\cdot}004$ nearly; which also gives

$$\frac{1}{\nu \epsilon} = {\cdot}68.$$

Hence it appears that $\frac{n'}{\gamma}$ can never exceed $\frac{{\cdot}88}{18{\cdot}6}$ or ${\cdot}047$, a small quantity; but $\frac{n}{\gamma}$ may be greater than, equal to, or less than unity, according to the value of q, or the thickness of the earth's crust.

§. *Final Equations, giving the Numerical Values of x and y.*

We may now proceed to the substitution of the values found in the last section in the coefficients of equations E, F, G, and H (Art. 18.). I shall begin with equation E.

26. The coefficients of $\sin 2 (n t + \lambda)$ is

$$\left\{ -\frac{B}{2n} + \frac{\gamma_1}{\gamma^2} \frac{1}{1 - \left(\frac{n}{\gamma}\right)^2} \left(\frac{\gamma}{n} \frac{B}{D} - 1\right) \frac{D}{2}. \right.$$

Its value depends on that of $\frac{n}{\gamma}$, which may either be much less than unity, equal to unity, or greater than unity, according to the value of the ratio (q) which the outer bears to the inner radius of the shell (Art. 25.).

1. Let the shell be thin, or q nearly $= 1$; then will $\frac{n}{\gamma}$ be small (Art. 25.). Consequently the coefficient becomes

$$-\left(1 - \frac{\gamma_1}{\gamma}\right)\frac{B}{2n}$$

$$= -\frac{\gamma_2}{\gamma} \cdot \frac{B}{2n}$$

$$= -\frac{q^5 - 1}{q^5} \cdot \frac{B}{2n}$$

$$= -\frac{3\varepsilon}{4\nu} \sin I \cos I.$$

2. Let the thickness of the shell be such that $\frac{n}{\gamma} = 1$ nearly. Then (Art. 25.)

$$2\frac{q^5 - 1}{q^5}\frac{1}{\nu\varepsilon} = 1 \text{ nearly},$$

$$q = \left(\frac{2}{2 - \nu\varepsilon}\right)^{\frac{1}{5}} \text{ nearly},$$

and

$$= (3{\cdot}71)^{\frac{1}{5}} = 1{\cdot}3 \text{ nearly},$$

which determines the corresponding value of the ratio of the inner and outer radii of the shell. I shall reserve this case for a distinct consideration in the sequel.

3. Let $\frac{n}{\gamma}$ be greater than unity. If the shell be so thick that q becomes considerable, γ_1 will become small, and the coefficient will become

$$-\frac{B}{2n}$$

$$= -\frac{3\varepsilon}{4\nu} \sin I \cos I$$

(q being considerably greater than unity). This value is identical with that found in the former case.

The coefficient of $\sin 2\,(n' t + \lambda')$ $\left(\text{since } \frac{n'}{\gamma} \text{ is always small}\right)$ becomes

$$-\frac{\gamma_2}{\gamma}\frac{B'}{2n'} = -\frac{q^5 - 1}{q^5} \cdot \frac{B'}{2n'}$$

$$= -\frac{3}{4}\frac{\varepsilon}{\sqrt{(\sigma + 1)}} \cdot \frac{\tau}{T'} \cos 2\,I \sin 2\,i.$$

The coefficient of $\cos 2\,\gamma\, t$ consists of two parts, of which the latter $\left(\text{since } \frac{n'}{\gamma} \text{ is small}\right)$

reduces itself to

$$\frac{\gamma_1}{\gamma^3} \cdot \frac{D'}{2} \sin 2\lambda';$$

and in like manner, when $\frac{n}{\gamma}$ is small, (or the thickness of the shell small) the first part becomes

$$\frac{\gamma_1}{\gamma^3} \cdot \frac{D}{2} \sin 2\lambda,$$

and the whole coefficient becomes

$$= \frac{1}{q^3} \cdot \frac{3}{2} \left\{ \frac{\sin I}{\nu^2} \cdot \sin 2\lambda - \frac{\sin I \sin 2i}{2\nu^2(\sigma+1)} \sin 2\lambda' \right\}.$$

The coefficient of $\sin 2\gamma t$ becomes $\left(\text{if } \frac{n}{\gamma} \text{ be small}\right)$

$$-\left\{ \frac{\gamma_1}{\gamma^3} \cdot \frac{B}{2} \cos 2\lambda + \frac{\gamma_1}{\gamma^3} \frac{B'}{2} \cos 2\lambda' - \frac{\gamma_1}{\gamma^3} \frac{A}{2} \right\}$$

$$= -\frac{1}{q^3} \frac{3}{2} \cdot \left\{ \frac{\sin I \cos I}{\nu^2} \cdot \cos 2\lambda + \frac{\cos 2I \sin 2i}{2\nu^2(\sigma+1)} \cos 2\lambda' \right.$$

$$\left. - \frac{\sin I \cos I}{\nu^2} - \frac{\sin I \cos I \cos^2 i}{\nu^2(\sigma+1)} \right\}.$$

These two coefficients being affected with the factor $\frac{1}{q^3}$ are very much diminished when q becomes considerable.

The coefficient of $t = \frac{\gamma_2}{\gamma}$ A, and becomes

$$\frac{q^5 - 1}{q^5} A$$

$$= \frac{3\pi\epsilon}{\nu} \sin I \cos I \left\{ \frac{1}{T} + \frac{1}{\sigma+1} \cdot \frac{\nu}{\nu'} \cos^2 i \frac{1}{T'} \right\}.$$

The constant term becomes

$$\frac{3\epsilon}{4\nu} \sin I \cos I \sin 2\lambda + \frac{3\epsilon}{4\nu'(\sigma+1)} \cos 2I \sin 2i \frac{\tau}{T'} \sin 2\lambda'.$$

Taking the expression for y, the coefficient of $\cos 2(nt + \lambda)$ becomes, when $\frac{n}{\gamma}$ is small,

$$-\frac{\gamma_2}{\gamma} \frac{D}{2n}$$

$$= -\frac{3\epsilon}{4\nu} \sin I.$$

This is also true when q becomes considerable.

The coefficient of $\cos 2(n't + \lambda')$ becomes

$$-\frac{\gamma_2}{\gamma} \cdot \frac{D'}{2n'}$$

$$= \frac{3\epsilon}{4\nu'(\sigma+1)} \cdot \cos I \sin 2i \frac{\tau}{T'}.$$

The numerical values of the coefficients of $\sin 2\gamma t$ and $\cos 2\gamma t$ are respectively the same as those of $\cos 2\gamma t$ and $\sin 2\gamma t$ in the expression for x.

The constant term becomes

$$\frac{3\varepsilon}{4\nu}\sin \mathrm{I}\cos 2\lambda - \frac{3\varepsilon}{4\sqrt{(\sigma+1)}}\cos \mathrm{I}\sin 2i\frac{\tau}{\mathrm{T}'}\cos 2\lambda'$$
$$+\frac{1}{q^5}\left\{\frac{3}{2\nu^2}\sin \mathrm{I}\cos \mathrm{I} + \frac{3}{2\nu^2(\sigma+1)}\cos^2 i\right\}.$$

27. Hence we obtain the following expressions for x and y, for any thickness of the shell for which $\frac{n}{\gamma}$ is small.

$$\begin{aligned}
x = &-\frac{3\varepsilon}{4\nu}\sin \mathrm{I}\cos \mathrm{I}\sin 2(nt+\lambda) - \frac{3}{4}\frac{\varepsilon}{\sqrt{(\sigma+1)}}\cdot\frac{\tau}{\mathrm{T}'}\cos 2\,\mathrm{I}\sin 2i\sin 2(n't+\lambda') \\
&+\frac{1}{q^5}\cdot\frac{3}{2}\left\{\frac{\sin \mathrm{I}}{\nu^2}\sin 2\lambda - \frac{\sin \mathrm{I}\sin 2i}{2\nu^2(\sigma+1)}\sin 2\lambda'\right\}\cos 2\frac{q^5}{q^5-1}\pi\varepsilon\frac{t}{t_1} \qquad \text{(I.)} \\
&-\frac{1}{q^5}\cdot\frac{3}{2}\left[\begin{array}{l}\dfrac{\sin \mathrm{I}\cos \mathrm{I}}{\nu^2}\cos 2\lambda + \dfrac{\cos 2\,\mathrm{I}\sin 2i}{2\nu^2(\sigma+1)}\cos 2\lambda' \\ -\dfrac{\sin \mathrm{I}\cos \mathrm{I}}{\nu^2} - \dfrac{\sin \mathrm{I}\cos \mathrm{I}\cos^2 i}{\nu^2(\sigma+1)}\end{array}\right]\sin 2\frac{q^5}{q^5-1}\pi\varepsilon\frac{t}{t_1} \\
&+\frac{3\pi\varepsilon}{\nu}\sin \mathrm{I}\cos \mathrm{I}\left\{\frac{t}{\mathrm{T}} + \frac{1}{\sigma+1}\cdot\frac{\nu}{\nu'}\cos^2 i\frac{t}{\mathrm{T}'}\right\} + \mathrm{C};
\end{aligned}$$

$$\begin{aligned}
y = &-\frac{3\varepsilon}{4\nu}\sin \mathrm{I}\cos 2(nt+\lambda) + \frac{3\varepsilon}{4\sqrt{(\sigma+1)}}\cos \mathrm{I}\sin 2i\frac{\tau}{\mathrm{T}'}\cos 2(n't+\lambda') \\
&+\frac{1}{q^5}\cdot\frac{3}{2}\left\{\frac{\sin \mathrm{I}}{\nu^2}\sin 2\lambda - \frac{\sin \mathrm{I}\sin 2i}{2\nu^2(\sigma+1)}\sin 2\lambda'\right\}\sin 2\frac{q^5}{q^5-1}\pi\varepsilon\frac{t}{t_1} \qquad \text{(K.)} \\
&+\frac{1}{q^5}\cdot\frac{3}{2}\left[\begin{array}{l}\dfrac{\sin \mathrm{I}\cos \mathrm{I}}{\nu^2}\cos 2\lambda + \dfrac{\cos 2\,\mathrm{I}\sin 2i}{2\nu^2(\sigma+1)}\cos 2\lambda' \\ -\dfrac{\sin \mathrm{I}\cos \mathrm{I}}{\nu^2} - \dfrac{\sin \mathrm{I}\cos \mathrm{I}\cos^2 i}{\nu^2(\sigma+1)}\end{array}\right]\cos . 2\frac{q^5}{q^5-1}\pi\varepsilon\frac{t}{t_1} + \mathrm{C}';
\end{aligned}$$

when C and C′ are small constant terms whose values are given above.

These are the expressions for x and y when $\frac{n}{\gamma}$ is small, or the thickness of the shell comparatively small. When the thickness is such that q becomes considerably greater than unity, the terms involving sine and cosine of $2\frac{q^5}{q^5-1}\pi\varepsilon\frac{t}{t_1}$ may be entirely omitted, and the expressions will then be true in this case.

28. Since the motion of the interior fluid cannot be subjected to observation, it would be useless to make the substitution of numerical values in equations (G.) and (H.) (Art. 18.). We may remark, however, that the motion of the axis of instantaneous rotation of the fluid will be exactly similar to that of the axis of the shell, and of the same order, as is easily seen by comparing the two equations just mentioned with the equations (E) and (F) of the same article.

§. *Interpretation of the Final Expressions for x and y* (Art. 27).

29. The terms in x and y which have $2\,(n\,t + \lambda)$ for their arguments are the two parts of solar nutation. They are identical with the expressions for solar nutation deduced on the hypothesis of the earth's being a homogeneous solid spheroid. It will be recollected that this excludes the particular case in which the outer and inner radii are in a certain ratio to each other (Art. 26. 2.).

The terms of which the argument is $2\,(n'\,t + \lambda')$ are the two parts of lunar nutation, which are, for any thickness of the shell, identical with the expressions deduced on the hypothesis of the earth's being entirely solid and homogeneous.

The term in x which constantly increases with t is the luni-solar precession. It is again identical with that found on the hypothesis just mentioned. We may also remark, that this agreement is independent of any approximation depending on the smallness of such quantities as $\frac{n}{\gamma}$ or $\frac{n'}{\gamma}$, and is consequently more accurately true than in the expressions for nutation.

30. The terms of which the common argument is $2\,\frac{q^5}{q^5 - 1}\,\pi\,\epsilon\,\frac{t}{t_1}$ or $2\,\gamma\,t$ indicate an inequality depending entirely on the fluidity of the interior mass. If we denote the coefficients in these terms by G and H, and neglect the other terms, we shall have

$$x = \mathrm{G}\cos 2\,\gamma\,t - \mathrm{H}\sin 2\,\gamma\,t,$$
$$y = \mathrm{G}\sin 2\,\gamma\,t + \mathrm{H}\cos 2\,\gamma\,t;$$

or

$$x = \sqrt{\mathrm{G}^2 + \mathrm{H}^2}\cos 2\,(\gamma\,t + \mathrm{K}),$$
$$y = \sqrt{\mathrm{G}^2 + \mathrm{H}^2}\sin 2\,(\gamma\,t + \mathrm{K});$$

$\left(\text{where } \tan\ 2\mathrm{K} = \frac{\mathrm{H}}{\mathrm{G}}\right)$ which show that x and y would thus be the coordinates of a point moving uniformly in a circle; and if R be its radius

$$\mathrm{R} = \sqrt{\mathrm{G}^2 + \mathrm{H}^2};$$

and the period of revolution would $= \frac{\pi}{\gamma}$

$$= \frac{q^5 - 1}{q^5}\,\frac{t_1}{\epsilon}.$$

It appears by the expressions for G and H, that these quantities will be the greatest when q^5 is least, i. e. when the shell is very thin; but even in that case they will not rise to magnitudes greater than those of the order of the solar nutation; and when the thickness of the shell becomes considerable, and q differs considerably from unity, the inequality will become quite insensible.

There is a corresponding inequality in the motion of the axis of instantaneous rotation of the fluid, indicated by corresponding terms in x' and y'. Comparing them with the terms in x and y, we find (omitting the other terms)

$$x' = -\frac{\gamma_2}{\gamma_1} \mathrm{G} \cos 2\gamma t + \frac{\gamma_2}{\gamma_1} \mathrm{H} \,.\, \sin 2\gamma t,$$

$$y' = -\frac{\gamma_2}{\gamma_1} \mathrm{G} \sin 2\gamma t - \frac{\gamma_2}{\gamma_1} \mathrm{H} \cos 2\gamma t;$$

or

$$x' = -\frac{\gamma_2}{\gamma_1} \sqrt{\mathrm{G}^2 + \mathrm{H}^2} \cos 2(\gamma t + \mathrm{K}),$$

$$y' = -\frac{\gamma_2}{\gamma_1} \sqrt{\mathrm{G}^2 + \mathrm{H}^2} \sin 2(\gamma t + \mathrm{K}).$$

Consequently the locus of $x'\,y'$ would also be a circle described about the common origin of $x\,y$, x' and y', and having a radius $= \frac{\gamma_2}{\gamma_1}$ R. By this inequality, therefore, alone the points P and P′ would describe circles about the same centre in the same periodic time, with radii in the ratio of $\gamma_1 : \gamma_2$, and differing in angular position by 180°.

The motion now described is that which would obtain if no extraneous disturbing forces acted on the spheroid, and the axes of instantaneous rotation of the shell and fluid should be separated by a small angle. It is a case of rotatory motion which has not before been investigated.

31. The case which remains for our consideration is that in which $\gamma = n$ nearly (Art. 26.).

In our previous investigations we have supposed the spheroidal shell to be of a definite constant thickness, and not to increase with the time. In the case of the earth, however, in which the solidity of the shell is conceived to be due to the external refrigeration of the mass, this thickness must be constantly increasing, though the rate of increase must be excessively slow; and our results, as expressed in equations (E), (F), (G), and (H) (Art. 18.), will be true for any instantaneous value of q, or of the thickness of the shell. So far, however, as the inequalities are of appreciable magnitude, we have seen that they are independent of particular values of q, except in the case which we have now to consider.

Referring to equation (E) (Art. 18.) we find that when $\gamma - n$ is very small, we have (taking what then become the most important periodical terms)

$$x = \frac{\gamma_1}{\gamma^2 - n^2}\left(\frac{\gamma}{n}\frac{\mathrm{B}}{\mathrm{D}} - 1\right)\frac{\mathrm{D}}{2} \sin 2(nt + \lambda)$$

$$- \frac{\gamma_1}{\gamma^2 - n^2}\left(\frac{\gamma}{n}\frac{\mathrm{B}}{\mathrm{D}} - 1\right)\frac{\mathrm{D}}{2} \sin 2\lambda \cos 2\gamma t$$

$$+ \frac{\gamma_1}{\gamma^2 - n^2}\left(\frac{\gamma}{n} - \frac{\mathrm{B}}{\mathrm{D}}\right)\frac{\mathrm{D}}{2} \cos 2\lambda \sin 2\gamma t.$$

Now $\frac{\gamma_1}{\gamma^2 - n^2} = \frac{\gamma_1}{\gamma + n} \cdot \frac{1}{\gamma - n} = \frac{\gamma_1}{2n} \cdot \frac{1}{\gamma - n}$ (since $\gamma = n$ nearly);

also

$$\frac{\mathrm{B}}{\mathrm{D}} = \cos \mathrm{I}.$$

Hence putting $\frac{\gamma_1}{2n}(1 - \cos I)\frac{D}{2} = h$, we have

$$x = -\frac{h}{\gamma - n}\sin 2(nt + \lambda)$$
$$+ \frac{h}{\gamma - n}\left\{\sin 2\lambda \cos 2\gamma t + \cos 2\lambda \sin 2\gamma t\right\}$$
$$= \frac{h}{\gamma - n}\left\{\sin 2(\gamma t + \lambda) - \sin 2(nt + \lambda)\right\}$$
$$= 2h \cdot \frac{\sin 2(\overline{\gamma - n})t}{\gamma - n}\cos 2(nt + \lambda) \text{ very nearly,}$$

an expression which assumes the form $\frac{0}{0}$ when $\gamma = n$ accurately. To put it under a more convenient form, assume t' a particular value of t, such that

$$2(\gamma - n)t' = \text{some multiple of } \pi$$
$$= 2m\pi;$$

and let $$t = t' + t'',$$
$$\gamma - n = s,$$

and when $$t = t',$$

let $$\gamma - n = s_1.$$

For the clearer interpretation of this term, let us first suppose the thickness of the shell, and therefore γ and s, to remain constant. We have

$$x = 2h\frac{\sin 2s_1(t' + t'')}{s_1}\cos 2(n\overline{t' + t''} + \lambda)$$
$$= \frac{2h}{s_1}\sin 2s_1 t'' \cos 2(nt'' + L).$$

In a similar manner we obtain

$$y = \frac{2h}{s_1}\sin 2s_1 t'' \cdot \sin 2(nt'' + L).$$

Since s_1 is supposed very small compared with n and the product $s_1 t''$ may be considered as nearly constant for any one year, in which time $\sin 2(nt'' + L)$ will pass through its period, and the solar nutation for that year will depend on

$$\frac{2h}{s_1}\sin 2s_1 t''.$$

Consequently from the time when $t = t'$ or $t'' = 0$, this nutation will increase every year till $2st'' = \frac{\pi}{2}$, after which it will again decrease. We should thus have a *secular inequality* in the solar nutation, of which the whole period would be $\frac{\pi}{s_1}$, and of which the greatest value, with reference either to x or y, would be $\frac{2h}{s_1}$.

In the actual case in which γ constantly decreases, suppose that at the time t'' from the time t',

$$s = \gamma - n = s_1 - r\,t'',$$

r denoting the rate of decrease of γ, and being taken constant during a small augmentation in the thickness of the shell. Then shall we have

$$x = \frac{2\,h}{s_1 - r\,t''} \sin \overline{2\,(s_1 - r\,t'')\,t''} \,.\, \cos 2\,(n\,t + \mathrm{L}),$$

with a similar expression for y.

This expression indicates a *secular variation* in the *secular inequality* just noticed, which increases with the diminution of $s_1 - r\,t''$, or the increase of t'', till $r\,t''$ becomes greater than s_1, after which the inequality will constantly decrease again.

The determination of r would require that of the rate at which the thickness of shell may increase. We have

$$\gamma - n = s = s_1 - \frac{d\,s}{d\,t}\,t''$$

$$= s_1 - \frac{d\,\gamma}{d\,t}\,t'',$$

$$\therefore r = \frac{d\,\gamma}{d\,t}.$$

But

$$\gamma = \frac{q^5}{q^5 - 1}\,\pi\,s\,\frac{1}{t_1} \qquad \text{(Art. 25.)}$$

$$= \frac{a_1{}^5}{a_1{}^5 - a^5}\,\frac{\pi\,s}{t_1};$$

$$\frac{d\,\gamma}{d\,t} = 5\,\frac{a_1{}^5\,a^4}{(a_1{}^5 - a^5)^2}\,\frac{\pi\,s}{t_1} \cdot \frac{d\,a}{a\,t}$$

$$= 5\,\frac{q^5}{(q^5 - 1)^2}\,\frac{\pi\,s}{t_1} \cdot \frac{1}{a} \cdot \frac{d\,a}{a\,t}.$$

Let $\delta\,a$ = increase of thickness in time T (one year); then

$$\delta\,a = \frac{d\,a}{d\,t}\,\mathrm{T},$$

and

$$r = 5\,\frac{q^5}{(q^5 - 1)^2}\,\frac{\pi\,s}{\mathrm{T}\,t_1} \cdot \frac{\delta\,a}{a}$$

$$= \cdot 35\,\frac{\delta\,a}{a} \cdot \frac{1}{\mathrm{T}\,t_1}$$

by the substitution of numerical values (Art. 26. 2.). Hence r may be known when $\frac{\delta\,a}{a}$ is determined.

Substituting for γ_1 its value $\frac{\pi\,s}{q^5 - 1}\,\frac{1}{t_1}$, and for n its value $\frac{2\,\pi}{\mathrm{T}}$, we have

$$h = \frac{\nu\,s}{8} \cdot \frac{1}{q^5 - 1} \cdot (1 - \cos \mathrm{I})\,\mathrm{D}.$$

We may here, without sensible error, put for q its particular value $\left\{\left(\frac{2}{2-\nu s}\right)^{\frac{1}{5}} \text{(Art. 26.2.)}\right\}$ when $\gamma = n$. We thus obtain

$$h = \cdot 02 \frac{\pi}{T} \text{ nearly, } 1'' \text{ being the angular unit.}$$

Also (Art. 25.)

$$\gamma - n = \frac{q^5}{q^5 - 1} \pi s \frac{1}{\lambda_1} - \frac{2\pi}{T},$$

$$= \left(\frac{q^5}{q^5 - 1} \nu s - 2\right) \frac{\pi}{T},$$

$$= \left(\frac{q^5}{q^5 - 1} 1 \cdot 464 - 2\right) \frac{\pi}{T}.$$

Hence the greatest value of the secular inequality $= \frac{2h}{\gamma - n}$,

$$= \left(\frac{\cdot 04}{\frac{q^5}{q^5 - 1} 1 \cdot 464 - 2}\right)'';$$

and the whole period of the inequality $= \frac{\pi}{\gamma - n}$,

$$= \frac{T}{\frac{q^5}{q^5 - 1} 1 \cdot 464 - 2}.$$

If we assign any particular value to the above expression for $\frac{2h}{\gamma - n}$, we may easily determine the corresponding value of q, and of the thickness of the solid shell, and also the period of the inequality, supposing the thickness of the shell to remain very nearly the same during such period. Thus, suppose the greatest value of the inequality to be $5''$, we shall have

$$\frac{\cdot 04}{\frac{q^5}{q^5 - 1} 1 \cdot 464 - 2} = 5.$$

This gives

$$\frac{1}{q} = \cdot 77 \text{ nearly,}$$

or

$$a = \cdot 77\, a_1.$$

Also when $\gamma = n$ accurately, we have (if q' be the corresponding value of q)

$$\frac{q'^5}{q'^5 - 1} 1 \cdot 464 - 2 = 0,$$

which gives

$$\frac{1}{q'} = \cdot 768472,$$

or, if a' be the corresponding value of a,

$$a' = \cdot 768472 \,.\, a_1.$$

Therefore

$$a - a' = 6 \text{ miles approximately.}$$

The period would be about 125 years.

In order that these numerical results may be approximately true, the variation of $a - a'$ during the period of 125 years must be small compared with $a - a'$. If we suppose the thickness of our shell to increase at the same rate as that of the earth's crust in the process of its solidification, this will probably be true.

Again, if we suppose the inequality to amount to about 1000″, we obtain

$$a - a' = 130 \text{ feet nearly;}$$

and the period, supposing a constant, would be about 25,000 years, i. e. in one fourth of that period the part of solar nutation dependent on the term we are discussing would pass from zero to about 1000 seconds. If, however, we suppose the solid shell of our spheroid to increase in thickness at the same rate as the crust of the earth, the difference between a and a' would possibly not remain within the value just mentioned for nearly so long as 6000 years; in which case, supposing the inequality to be zero when $a - a'$ should equal about 130 feet, it could never afterwards amount to nearly 1000 seconds; nor could it have been previously so great, because its previous values must have corresponded to values of $a - a'$ less than the above value. Our investigation, however, does not tell us whether 120 or 130 feet would be near the value of $a - a'$ the last time the secular inequality should vanish before a became $= a'$, and consequently we cannot say with certainty that 1000 seconds would be the extreme limit to which the inequality would attain. In fact, the exact determination of this limit would require the very accurate determination of a as a function of t, which cannot be known in the case of the earth's crust without an accurate knowledge of the conductive power of the matter which constitutes it. From the small value, however, of $a - a'$ and great length of the period corresponding to the maximum of 1000″ for the inequality we have been considering, it may perhaps be deemed extremely improbable that it should ever exceed that value in the case of the earth. The duration of time for which the effect of the cause we are discussing on solar nutation would be sensible to observation would be, that necessary for the thickening of the earth's crust so to increase that $a - a'$ should pass from $+$ (6 or 8 miles) to $-$ (6 or 8 miles), and might therefore be approximately determined if the quantity denoted by r in this article were known.

§. *Degree of Approximation in the preceding Results.*

The results at which we have arrived above rest on the hypothesis of the instantaneous planes of rotatory motion being parallel to the tangent plane to the interior surface of the shell at B′ (Art. 8. III.); and it remains for us to consider the degree of approximation to the actual motion which has been thus obtained. It will be recollected that, on this hypothesis, the centrifugal force produces a force $Z = 2\,\omega^2 \varepsilon\, \beta\,.\,x$ (Art. 10.), which alone is effective in producing motion in the fluid, this motion being

about the axis of y, and that which, combined with the angular motion about A B′, causes the angular motion in space of this latter axis. The value of Z has been found on the hypothesis of ω being constant, or of the rotatory motion about A B′ being the same as if the sections of the inner surface of the shell were circles instead of being ellipses of small eccentricity (Art. 9.); and the pressure on the inner surface of the shell depending on the centrifugal force has been calculated on the same hypothesis. It will be necessary therefore to examine the errors thus committed.

33. Let us conceive a closed cylinder entirely filled with fluid, which revolves uniformly about the axis of the cylinder with a velocity ω, and is not acted on by any external force. If the form of the cylinder be then changed without changing its volume, so that each section perpendicular to its axis shall become an ellipse of small eccentricity instead of being circular, it is manifest from the conditions of symmetry, that the angular motion of the fluid, though no longer uniform, will still be *steady* about the same axis, as in the circular cylinder. Consequently if p' be the pressure at any point on the surface of the elliptical cylinder, v' the velocity of the fluid at that point, we shall have

$$p' = \mathrm{C} - \frac{1}{2} v'^2;$$

and if p and v be any corresponding values of p' and v' (which may be taken for their mean values)

$$p = \mathrm{C} - \frac{1}{2} v^2,$$

and

$$p' = p - \frac{1}{2} (v'^2 - v^2).$$

Now the quantity of fluid which passes through any section of the elliptic cylinder made by a plane through its axis, must be constant, and therefore the velocity v' must vary inversely as r'*, the radius vector of the elliptic section from its centre. Therefore, if r be the value of r' when v is that of v' (i. e. the mean value of r')

$$v'^2 = v^2 \cdot \frac{r^2}{r'^2},$$

$$= v^2 \cdot \frac{r^2}{b'^2} (1 - 2\,\epsilon' \cos \theta'),$$

where b' is the axis minor of the elliptic section. Also

$$r = \frac{a' + b'}{2},$$

$$= b' \left(1 + \frac{\epsilon'}{2}\right);$$

and $$\frac{r^2}{b'^2} = 1 + \epsilon':$$

* There can be no doubt of this hypothesis being true, at least to a sufficient degree of approximation for our immediate purpose.

whence

$$v'^2 - v^2 . = v^2 \varepsilon' (1 - 2 \cos^2 \theta');$$

and

$$p' = p + \frac{1}{2} v^2 \varepsilon' \cos 2 \theta',$$

or, putting in the small term ωr for v,

$$p' = p + \frac{\omega^2}{2} r^2 \varepsilon' \cos 2 \theta'.$$

We have here taken r' and θ' as the polar coordinates of the elliptical section of the surface, but it is evident that this expression for the fluid pressure will be equally true for any point of the fluid of which r' and θ' are the co-ordinates, p and r being taken with reference to an ellipse passing through the point $(r' \theta')$ similar to the elliptic section of the cylinder, and similarly situated.

The case which presents itself in our actual problem is analogous to the one just considered, so far as regards the elliptical form of the sections made by the planes of rotatory motion, these planes being parallel to the tangent plane at B′ (fig. 2.). The common ellipticity of these sections is $\varepsilon \beta$ (Art. 9.), and, therefore, in finding the effect on the shell, of the pressure arising from the centrifugal force on the fluid in article 23., we ought to have used for p the pressure as found in the last article, p', or

$$p + \frac{\omega^2}{2} r^2 \varepsilon \beta \cos 2 \theta'.$$

This, however, would only introduce into p a term of the order $\varepsilon \beta$, and which, therefore, may be omitted, as shown in the investigation just referred to (Art. 23.). Also, taking this expression for p' as applicable to any point of the fluid (as explained in the preceding paragraph), it is easily seen that the force Z $(= \omega^2 \varepsilon \beta . x)$ will only be altered, in consequence of the ellipticity of the sections of the shell, by a quantity small compared with itself, and which may, therefore, be neglected. Our results, then, will be quite accurate to the degree of approximation to which we have proceeded, assuming the parallelism of the planes of rotatory motion to the tangent plane at B′. I shall now proceed to this point.

34. It has been shown (Art. 15.) that the angular velocity of A B′ in space $= \omega . \varepsilon \beta$, and also (Art. 28.) that the angular velocity of A B is of the same order as that A B′ i. e. of the order $\varepsilon \beta$. The angular motion of A B′ (Arts. 12 ..... 15.) is due entirely to the *obliquity* of the planes of rotatory motion of the fluid particles, and the above value of it is calculated on the hypothesis of these planes of rotation being parallel to the tangent plane at B′. It is easy to see, however, that if this hypothesis be not accurate, the value of γ_2 (Art. 16.) and therefore of the angular velocity of A B′ (Art. 15.) will still be quantities of the same order respectively as the calculated values which have been given, so long as the planes of rotation shall make angles with planes perpendicular to A B′ which, instead of being = to ι (Art. 8.), shall be merely of the same order of magnitude. Without assuming, therefore, the accuracy of the above

hypothesis, we may still assert that the angular velocities of A B and A B′ will necessarily be of the order $\epsilon\,\beta$.

The positions of the planes of rotatory motion will be affected by the change of position of the shell, or of A B, and also by that of A B′. It will be convenient to consider these cases separately, first, supposing A B′ fixed while A B moves, and then taking A B fixed and A B′ in motion.

In the assumption, that A B′ shall be at rest, it is meant that it shall here be considered as unaffected by the angular motion which has been investigated, and which is due to the obliquity of the planes of rotatory motion. Our first object will be to examine whether any motion will be communicated to A B′ as the direct and immediate consequence of the motion of the shell, and independently of centrifugal force in the fluid, to which the previously calculated velocity of A B′ is entirely due; also A B′ ought strictly to be considered as *the line of quiescent fluid particles*, in which sense it will not necessarily be a straight line, as we have hitherto considered it in calculating the effects of centrifugal force on the fluid. It will, therefore, be necessary to examine the degree of its deviation from rectilinearity.

Suppose the shell to be at first in the position represented by the dotted line (fig. 2.) and then to be brought into that represented by the continuous line, A B, coinciding at first with A B′. Then while A B moves through the angle B′ A B (β), the normal motion (N N″) at any point (N) cannot exceed a quantity of the order $\epsilon\,\beta$, as is easily shown*. Also it is evident that (considering only the velocity due to the displacement of the shell) the ratio

$$\frac{\text{vel. of fluid particle at N}}{\text{vel. of point B of the shell}}$$

must be a quantity of the same order as $\frac{\text{N N}''}{\text{B}'\text{B}}$, i. e. of the order ϵ; and it is easily seen that for any particle in the interior of the fluid the motion cannot exceed a quantity of that order. Also the conditions of symmetry will evidently require that the particle at A should remain at rest.

If the spheroidal axis, instead of moving from A B′ to A B, move from A B to A $\mathfrak{B}$, the same conclusion respecting the ratio of the velocity of any fluid particle to the velocity of B will still be true, as is easily seen.

Let v_1 be the velocity of B, v that of a particle Q, from the cause we are considering, the distance of Q from A being r, and its distance from the axis A B′ $= \varrho$. Since v will be of the order $\epsilon\, v_1$ let $v = k\,\epsilon\,\frac{r}{a}\,v_1$, where k is a numerical quantity, the value of which may depend on the position of the particle. Also the velocity of Q from the motion of rotation round A B′ $= \omega\,\varrho$. Consequently, if Q be so situated that these

* N ν must manifestly vanish with ϵ as well as with β, and the expression for it must, therefore, involve some power of ϵ as a factor.

velocities are impressed upon it along the same line and in opposite directions, the whole velocity of Q will

$$= k\,\varepsilon\,\frac{r}{a}\,v_1 - \omega\,\varrho,$$

and if this $= 0$, Q will be a point in the line of quiescent particles. This gives us

$$\frac{\varrho}{r} = \frac{k\,\varepsilon}{\omega}\cdot\frac{v_1}{a}:$$

$\frac{v_1}{a}$ is the angular velocity in space of A B, and is, therefore, of the order $\varepsilon\,\beta$, and $= k'\,\varepsilon\,\beta$ (suppose). Consequently, the angular deviation of Q from A B′ $\left(\text{which} = \frac{\varrho}{r}\right)$

$$= \frac{k\,k'}{\omega}\cdot\varepsilon^2\,\beta,$$

a quantity extremely small compared with β. A B′ may, therefore, be considered as a straight line, to the required degree of approximation. Also the angular velocity of any point in A B′ due to the cause here considered, is of the order $\varepsilon^2\,\beta$; it may, therefore, be neglected in comparison with the angular velocity ($\omega\,\varepsilon\,\beta$) of A B′ previously determined (Art. 15.).

35. We may now proceed to consider the positions of the planes of rotation of different particles of the fluid when B does not coincide with B′. It has been shown (Art. 8. III.) that the instantaneous positions of these planes must approximate more or less to parallelism with the tangent plane at B′. This approximation, however, may be different for different fluid particles, in which case it will manifestly be most accurate for particles nearest to B′ and b', and less so for those nearer the plane of the equator. In considering, therefore, the degree of approximation it may be convenient to refer to a *mean plane* of rotation, or an imaginary plane whose inclination is the mean of the inclinations of all the planes of rotation of different particles.

As B moves about B′ the tangent plane at B′ will move from one position to another, revolving about its ultimate intersection with the consecutive position, as an axis of instantaneous rotation, with a certain angular velocity. If B moved uniformly round B′ (as would be the case if the motion were due entirely to the centrifugal force on the fluid (Art. 30.)), the angular velocity of the tangent plane would be uniform; and since the motion of the fluid would then be steady, the angular motion of the planes of rotation would also be uniform, and the angle thus described in a unit of time by the mean plane of rotation might be taken as a measure of the whole *constraining force* (arising from the reaction of the solid shell on the fluid) which produces this particular motion. In the actual case the motion of B will not be uniform; but since the *variation* of its motion will be extremely slow, the propositions just enunciated will still be approximately true for any comparatively limited period, and we may still take as a measure of the instantaneous *constraining force*, the angle actually described by the mean plane of rotation, in the manner above explained, in a unit of time.

Now if A B should move from A B′ through an angle β, it is easy to show that the tangent plane at B′ must move through an angle of the order $\epsilon\,\beta$; and it is easily seen likewise that if A B move in any other direction, as from A B to A $\mathfrak{B}$ through an angle β', the angle moved through by the tangent plane at B′ will be of the order $\epsilon\,\beta'$. In every case, therefore,

$$\text{ang. vel. of the tang. plane} = k'\,\epsilon\,.\,\text{ang. vel. of A B}$$
$$= k\,\epsilon^2\,\beta$$

where k is some finite numerical quantity. Consequently, since the angle described by the mean plane of rotation in a unit of time cannot be greater than this, that angle, and therefore the instantaneous *constraining force*, must be of the order $\epsilon^2\,\beta$.

36. Let us now consider the relation between the *constraining force* and the angle which the instantaneous mean plane of rotation makes with the instantaneous tangent plane at B′. Let ι denote, as heretofore, the angle between the tangent plane and a plane perpendicular to A B′, ι' that between the tangent plane and the mean plane. Now instead of the shell moving on continuously, let us conceive its motion to cease at any instant, and consider its action, when thus at rest, on the fluid mass. If we take a fluid particle near to B′ and in contact with the surface, B′ may be considered as the centre of its rotatory motion, provided its distance from that point be not less than a quantity of the order $\epsilon\,\beta$ (since the angular displacement of B′ cannot exceed a quantity of the order $\epsilon^2\,\beta$). Consequently, if the motion of the plane should cease at any instant, as above supposed, it is manifest that the plane of motion of this particle must be immediately constrained to coincide with the tangent plane at B′, i. e. the constraining force upon it must have been such as to change its plane of motion through an angle of the order ι' in a very short space of time. If we take a particle in contact with the surface, rather more remote from B′, the same conclusion must be approximately true, though a somewhat greater time may be necessary to produce an equal change in the position of its plane of rotation. And similarly if we take a particle in contact with the shell at any point, for instance, between B′ and N′, the reaction of the surface must produce a similar effect on its plane of rotation; and moreover, it is easily seen that if the shell be supposed to remain thus at rest for a whole revolution, for example, the effect produced in that time must be of the same order of magnitude as that for particles near to B′. Precisely the same effects must take place about b' and between b' and L′, whence it will necessarily follow that similar effects and of the same order of magnitude must be produced on the planes of motion of the particles constituting the interior part of the fluid intermediate to the portions N′ n' and L′ ℓ' of the surface. Similar effects must also be produced on the portion of the fluid exterior to that just specified, though these effects may decrease in magnitude as the particles are situated nearer to C and c.

Hence then it follows that (taking, for the greater distinctness, one day for the unit of time) if B, and therefore the tangent plane at B′, were to remain at rest for a unit of time, the *constraining force*, estimated as above described, arising from the reaction

of the shell on the fluid, would be such as to cause the mean plane of rotation to move through an angle of the same order of magnitude as the instantaneous angle between that plane and the tangent plane at B′, i. e. of the order ι'. But it is evident that if the tangent plane at B′, instead of remaining at rest, as we have here conceived it to do, have its actual motion *from* the instantaneous mean plane, the whole effect in one day on the plane of rotation of a particle near to B′ or b' must be greater than if the surface had remained at rest; and the same conclusion must also be true for particles more remote from B′ or b'. Consequently the angle through which the mean plane of rotation moves in one unit of time, must, *à fortiori*, in the actual motion be of the same order as ι', i. e. the *constraining force*, estimated by this angle, must be of the order ι'. But it has been already shown (Art. 35.) that this force must be of the order $\epsilon^2 \beta$. Consequently ι' must be of the order $\epsilon^2 \beta$; or, since $\iota = 2 \epsilon \beta$, the angle between the mean plane of rotation and the tangent plane at B′ is a small quantity of a higher order than ι, which proves the truth of our assumption, in the previous investigations, of the coincidence of these planes to the required degree of approximation.

37. We have hitherto considered B to move while B′ remains at rest; let us now consider B′ to move while B remains at rest. Suppose A B′ to move through an angle β' in its motion in space which has been previously investigated, B′ then coming to $\mathfrak{B}'$. If the shell were spherical, the angle between the tangent planes at B′ and $\mathfrak{B}'$ respectively would $= \beta'$, and in the spheroid the angle between these planes can differ from β' only by a quantity of the order $\epsilon \beta'$. Consequently, in order that the mean plane of rotation should be always parallel to the tangent plane at the extremity of the axis of rotation of the fluid, it must move through an angle of the same order as that (β') described by that axis; whereas when A B moves through an angle β', the corresponding angular motion of the mean plane of rotation is (as we have shown) only of the order $\epsilon \beta'$. We must examine how this angular motion of the mean plane is produced when A B′ is in motion.

While the axis of instantaneous rotation in a rigid body changes its position in the body, the instantaneous planes of rotatory motion necessarily retain their perpendicularity to it, and therefore the angular motion of those planes is equal to that of the axis. Now we have shown (Art. 15.) that the change in the position of A B′ is produced in a manner exactly similar to that in a solid body, so that the same cause produces simultaneously the angular motion of A B′, and an equal angular motion of the planes of rotation; whence it is easily seen that the mean plane of rotatory motion when the axis has moved to $\mathfrak{B}'$, cannot, on this account alone, deviate from parallelism with the tangent plane at $\mathfrak{B}'$ by a quantity greater than of the order $\epsilon \beta'$. Consequently the additional angular velocity of the mean plane of motion necessary to preserve it in parallelism with the tangent plane cannot exceed a quantity of the order

$$\epsilon \,.\, \text{ang. vel. of A B}',$$

$$= K \epsilon^2 \beta.$$

This additional angular velocity must be produced by the *constraining force* as previously described. The force, therefore, in this case, as well as in the one previously considered, must be of the order $\epsilon^2 \beta$; whence it also follows, as before, that the angle between the instantaneous mean plane and the tangent plane at the extremity of the axis of rotatory motion of the fluid must be of the order $\epsilon^2 \beta$, a quantity to be neglected in comparison with ι.

Also, since ι' is small compared with ι in each of the above cases considered independently, it will be likewise true when the two causes act simultaneously, i. e. in the actual motion of B and B′ about each other. Hence all our previous results will be true to the required degree of approximation.

The following then are the results at which we have arrived, supposing the earth to consist of a homogeneous spheroidal shell (the ellipticities of the outer and inner surfaces being the same) filled with a fluid mass of the same uniform density as the shell.

I. The precession will be the same, whatever be the thickness of the shell, as if the whole earth were homogeneous and solid.

II. The lunar nutation will be the same as for the homogeneous spheroid to such a degree of approximation that the difference is inappreciable to observation.

III. The solar nutation will be sensibly the same as for the homogeneous spheroid, unless the thickness of the shell be very nearly of a certain value, something less than one-fourth of the earth's radius, in which case this nutation might become much greater than for the solid spheroid.

IV. In addition to the above motions of precession and nutation, the pole of the earth would have a small circular motion, depending entirely on the internal fluidity. The radius of the circle thus described would be greatest when the thickness of the shell should be least; but the inequality thus produced would not for the smallest thickness of the shell exceed a quantity of the same order as the solar nutation; and for any but the most inconsiderable thickness of the shell would be entirely inappreciable to observation.

In my next communication I propose to consider the case in which both the solid shell and the inclosed fluid mass are of variable density.

W. Hopkins.

Cambridge,
November 19, 1838.

XXI. *Description of a Hydropneumatic Baroscope.* *By* John Thomas Cooper, *Esq.* *Communicated by* William Thomas Brande, *Esq.*, *F.R.S. &c.*

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THE principle on which the instrument I am about to describe is constructed, is, *that the volume of a given quantity of air under a constant temperature, is inversely as the pressure to which it is subjected*; and the means I employ to estimate the change of volume which that quantity of air undergoes, by being subjected to differences of pressure caused by a change of elevation, are the determination of the difference of weight which a floating body is capable of sustaining in both situations. Thus, if a vessel containing a quantity of air and water be floated in water, and there be a communication between the water in the floating body and that in which it floats, it will follow, that when such an apparatus is subjected to diminished pressure, the air within the float will dilate, and cause a volume of water equal in amount to the dilatation of the air to be driven from the float; and the difference of weight which the floating body will sustain, will be the exact weight of the water expelled: if such an apparatus is subjected to an increased pressure, the air within it will contract, and consequently a quantity of water, from that in which it floats, will enter the float, and the diminished weight it is capable of sustaining will be the weight of the water which has entered the float, in consequence of the diminution of the volume of the air. It is by such means, with the instrument immediately to be described, and by the help of a very simple calculation, that I propose to determine the difference of level between any two places.

Plate X. fig. 1. represents the floating part, made of thin sheet brass, the body of which (*a*), in form the frustum of a cone, is nine inches long, two inches in diameter at one end, and one inch at the other, and capable of containing about fourteen cubic inches. In the centre of the widest end, a small stud of brass (*b*) is hard soldered, into which a brass wire (*c*) is screwed, an inch and three-eighths long, and about one twenty-fifth or one thirtieth of an inch in diameter: the other end of the wire is screwed into a brass stud in the middle of the convex side of a shallow cup (*d*), made also of brass, and as light as possible, so that it will retain its shape, and be capable of sustaining a weight of about eight hundred or one thousand grains.

At the lower and smaller end, a projecting rim (*e*) of brass is soldered, for the purpose of pouring out a portion of water from the interior with less risk of spilling; and into this end is screwed a brass plug *f*, which is required to be made of sufficient weight to sink the instrument in water with one hundred or one hundred and twenty grains

in the cup at the upper part, when it contains ten cubic inches of air. To the middle of the brass wire I affix a very small quantity of red sealing-wax (*g*), melted on it at that part, to serve as an index. Through the centre of the brass plug, a small hole (*h*), about the same diameter as the wire, is to be drilled, which forms a communication between the water in the inside of the float and that in which it floats. The reason I prefer the form of an inverted frustum of an acute cone is, that the greatest portion of the weight being considerably below the centre of gravity, causes the instrument to float with greater stability, and also enables it to carry more weight in the cup, without inclining to either side.

Fig. 2. is a representation of another part of the instrument, which serves as the case for containing the float, without any chance of its becoming injured, and at the same time retains the quantity of water necessary to render it buoyant. It consists of an inner vessel (*i*) made of thin sheet copper, nearly of the same form as the float, but somewhat larger in all its dimensions, being two inches and three quarters in diameter at top, one inch and three quarters at bottom, and eleven inches and a half deep; this is surrounded by a cylindrical case (*k*) of tin plate, three inches in diameter, and fourteen inches long. About three inches from the upper part of the outer case, are four holes (*l*) three quarters of an inch in diameter, having small hoods (*m*) of tin plate soldered over them, to prevent in a great measure the wind from blowing into them. The inner copper vessel is secured to the outer cylinder of tin plate by soft solder; and both are firmly soft soldered, water-tight, to a thick circular plate of brass (*n*), in which a circular hole (*o*) is turned, a little more than two inches in diameter, for the purpose of readily allowing the float to pass through it. In the inner edge of this circular hole a female screw is cut, in order that it may be closed either by a screw plug, or by the bottom of the brass box (*p*), which serves to carry the requisite grain weights. Across the top passes a piece of thick iron or brass wire (*q*), bent into the form of a loop, answering the purpose of a handle for carriage, or for suspending it. Fig. 3. represents the elevation and plan of a small spirit lamp (*r*), requisite, when an observation is to be made, to bring the water and the float with the water and air it contains always to the same temperature. The lamp is fixed by means of three wires (*sss*) into the middle of a rim of tin plate (*t*) rather smaller in diameter than the outer cylinder, and consequently allowing it easily to slip in, and there to be secured by three small studs with bayonet-joints. An open space or interval is left between the lamp and outer rim for the free admission of air necessary for the combustion of the spirit, three small balls (*v*) serving as feet, upon which the instrument rests, so as to admit sufficient air beneath. Fig. 5. represents a vessel of copper or tin plate, capable of containing 2525 grains of distilled or rain water, having, at its open extremity, a piece of strong glass tube cemented, upon which a mark (*w*) is to be made with a file or diamond, at the place occupied by the surface of the water when it contains the above quantity, at the temperature of 62° Fahr.

The mode of adjusting the instrument I have next to describe; it is as follows:

having unscrewed the plug *h* (fig. 1.), the float is first to be filled with rain or distilled water, and then as much water is to be poured out as will fill the measure (fig. 5.) to the mark on the glass tube: ten cubic inches of water having been thus abstracted from the float, the same volume of air will supply its place. If this operation be carefully performed, the same quantity of air within two or three hundredths of a cubic inch will always be admitted, which may be proved by the instruments sustaining nearly the same weight in the cup: the plug may then be screwed into its place.

The next step of the operation is to fill the inner conical vessel (fig. 2.) with rain or distilled water, and to bring it, by means of the lamp, to the temperature at which it is determined that all the observations are to be made. Presuming that the instrument will be principally employed, for the purposes intended, in the summer season, I would recommend the adjustment and all observations to be made at the temperature of 75° or 80° Fahr. The float is next to be placed with its smaller extremity uppermost into the warmed water, that the air and water which it contains may acquire the desired temperature. I may here remark that a thermometer capable of showing at least a quarter of a degree on Fahrenheit's scale ought to accompany the instrument under all circumstances, when experiments and observations are to be made. As soon as the float and its contents have acquired the requisite heat, (which may take from four to five minutes) the finger is to be placed over the small hole in the plug; then quickly withdrawing the float and replacing it inverted in the same vessel, it is adjusted for use.

In order to find the altitude by the weights to be applied in the cup, which may be considered as its scale, a long series of experiments has been made, of which the following is an abstract. The float, after being adjusted as above described, was placed in a cylindrical glass vessel containing water at 75° Fahr., the laboratory being kept at the same temperature during the time occupied by the experiments, which was generally from an hour to an hour and a half; and weights were then added to the cup, till the instrument was adjusted so that the index on the middle of the wire was coincident with the surface of the water. One hundred grains were then put into the cup, which caused the instrument to sink to the bottom of the glass vessel; and no more water was allowed to be in the glass, when the instrument had so sunk, than would stand a quarter of an inch above the mark on the wire. The cylindrical glass vessel was then placed on the plate of an air pump, and a barometer capable of reading to the $\frac{1}{1000}$th of an inch, having a cistern four inches diameter, attached to the smaller plate. The barometer was first read off and noted; a receiver was then placed over the vessel with the float, and exhaustion slowly made, until the float gradually rose from the bottom of the glass vessel, and the index on the stem coincided with the surface of the water. The barometer was then again read off and noted. A small portion of air being now let into the pump by the screw for that purpose, the float immediately sunk to the bottom. The screw, which allowed the admission of air, being made tight, the operation was repeated; and this was done a third time if the observations of the baro-

meter differed more than two or three thousandths of an inch: a mean of the three readings was taken for the correct one. The air was now admitted into the pump, and the receiver removed, when the barometer rose to its original elevation, unless any change of atmospheric pressure had occurred during the interval, which was seldom the case; but when it did happen, a mean of the two was taken. The same operation was gone through with 200, 300, 400, 500, 600, and 700 grains, the last weight being about as much as the instrument would steadily carry on the cup without showing a tendency to overbalance. Care was taken to remove from the glass vessel an equivalent portion of water on the addition of each 100 grains, otherwise it would have risen so high in the glass as to come in contact with the bottom of the brass cup, and thereby have frustrated the experiment.

Having given a general description of the instrument and mode of adjustment, I may now refer to fig. 6, which represents the apparatus in use, and which shows the difference of the level of the water in the interior of the float, and that which is exterior to it. Although the instrument contains ten cubic inches of air when subjected only to the atmospheric pressure, it will contain somewhat less than that quantity, by being pressed upon by a column of water, equal to the difference of the two levels, which is about five or six inches.

The following Table exhibits a series of experiments made with the air-pump, and the altitudes deduced from the barometrical depressions, calculated according to the formula and tables of Mr. Bailey.

(α).	(β).	(γ).	(δ).	(ε).
grs. feet.	grs. feet.	grs. feet.	grs. feet.	grs. feet.
100 = 1062	100 = 1076	100 = 1071	100 = 1040	100 = 1040
200 = 2123	200 = 2134	200 = 2113	200 = 2012	200 = 2095
300 = 3170	300 = 3136	300 = 3140	300 = 3097	300 = 3212
400 = 4129	400 = 4124	400 = 4101	400 = 4052	400 = 4084
500 = 5087	500 = 5098	500 = 5134	500 = 4988	500 = 5026
600 = 6027	600 = 6011	600 = 5992	600 = 5859	600 = 6159
700 = 6930	700 = 6907	700 = 6895		700 = 6925

Assuming the height to be of the form $A\,G + B\,G^2$, in which G denotes the number of grains in the cup *d*, the set of observations (α) gives the following equations:

$$\begin{aligned}
A + B &= 1062\\
2A + 4B &= 2123\\
3A + 9B &= 3170\\
4A + 16B &= 4129\\
5A + 25B &= 5087\\
6A + 36B &= 6027\\
7A + 49B &= 6930;
\end{aligned}$$

whence by the method of least squares, we readily find $A = 1085{\cdot}27$, $B = -13{\cdot}533$.

In the same manner the coefficients A, B have likewise been determined from the other sets of observations (β), (γ), (δ), (ε), and the following are the results obtained.

	A.	B.
From the set (α)	1085·27	−13·533
(β)	1093·39	−15·207
(γ)	1086·22	−14·110
(δ)	1065·35	−14·240
(ε)	1080·77	−12·190
Means . .	1082·20	−13·856

A mean has also been taken of the number of feet corresponding to each 100 grains, and from these are found

A.	B.
1076·38	−12·687

hence we have from mean observations

	A.	B.
	1076·38	−12·687
Mean of five sets	1082·20	−13·856
Means	1079·29	13·271

The height is, therefore, expressed by the formula $1079{\cdot}29\ G - 13{\cdot}271\ G^2$; or if g denote the number of single grains the height is

$$h = 10{\cdot}7929\,g - {\cdot}0013271\,g^2$$
$$= g\,(10{\cdot}7929 - {\cdot}0013271\,g)$$

The following table, showing the factor in the parenthesis, has been constructed, retaining only three places of decimals, to the nearest figure, which are all that can be required in practice; and it is only necessary to multiply this factor by the number of grains, g, to get the height, h, in feet.

TABLE I.

−100	10·926	100	10·660	300	10·395	500	10·129	700	9·864	900	9·599
− 90	·913	110	·647	310	·382	510	·116	710	·851	910	·585
− 80	·899	120	·634	320	·368	520	·103	720	·837	920	·572
− 70	·886	130	·620	330	·355	530	·090	730	·824	930	·559
− 60	·873	140	·607	340	·342	540	·076	740	·811	940	·546
− 50	·859	150	·594	350	·328	550	·063	750	·798	950	·532
− 40	·846	160	·581	360	·315	560	·050	760	·784	960	·519
− 30	·833	170	·367	370	·302	570	·037	770	·771	970	·506
− 20	·819	180	·554	380	·289	580	·023	780	·758	980	·492
− 10	·806	190	·541	390	·275	590	10·009	790	·745	990	·479
− 0	·793	200	·528	400	·262	600	9·997	800	·731	1000	·466
0	10·793	200	10·528	400	10·262	600	9·997	800	9·731		
10	·780	210	·514	410	·249	610	·983	810	·718		
20	·766	220	·501	420	·235	620	·970	820	·705		
30	·753	230	·488	430	·222	630	·957	830	·691		
40	·740	240	·474	440	·209	640	·944	840	·678		
50	·727	250	·461	450	·196	650	·930	850	·665		
60	·713	260	·448	460	·182	660	·917	860	·652		
70	·700	270	·435	470	·169	670	·904	870	·638		
80	·687	280	·421	480	·156	680	·880	880	·625		
90	·673	290	·408	490	·143	690	·877	890	·612		
100	·660	300	·395	500	·129	700	·864	900	·599		

TABLE II.

1	1
2	3
3	4
4	5
5	7
6	8
7	9
8	11
9	12

As an example of the application of the instrument to the determination of the height of one station above another, we will suppose that, having adjusted the instrument in the manner already described, it is found that 118 grains are required to be placed in the cup, in order to sink the float so that the index on the stem shall coincide with the surface of the water, when its temperature is 75° Fahr. Having noted these particulars, returned the weights into the box, and screwed it into its place, we then proceed to the other station, the altitude of which is greater. Here the water is first brought, by means of the lamp, to the same temperature, 75°, and then weights are put into the cup, until the instrument floats at the same mark; and we will suppose it requires 274 grains to effect this:

then 274
−118

156 grains, the difference of weights supported.

In Table I. 150 gives . 10·594
In Table II. 6 gives . − 8

10·586
which multiplied by . . . 156

63·516
52930
10586

gives . . . 1651·416 feet

for the difference of altitude between the two stations.

As another example, suppose that at the first station it requires 112 grains to sink the instrument to the mark, the temperature being as before 75°, and we then descend into a mine where it requires, at the same temperature, only 48 grains to bring it to the same position:

then 48
− 112

− 64 grains, the difference of weights supported:

this is minus, because the weight at the second station is less than at the first.

In Table I. − 60 gives 10·873
In Table II. − 4 gives + 5

10·878
which multiplied by 64

43512
65268

gives . . . . . 696,192 feet

for the depression of the second station below the first.

As a last example, I will give the following, which will in some degree serve to show the application of the instrument to the measurement of comparatively small quantities, and the amount of reliance that may be placed on the observations made with it and also on the formula.

From the ground floor to the attics of my house it requires as nearly as possible three grains to be added to the cup to balance the instrument.

If we now take from Table I. the number answering to 0	10·793
and subtract from it the number answering to 3 in Table II.	4
	10·789
multiply by the difference of weights	3
the product gives the height	= 32·367 feet

whereas by actual measurement it is 31 feet.

The delicacy and sensibility of the instrument are, however, such, that if it be very nicely adjusted to a tenth of a grain, it will readily show a difference of elevation of three or four feet.

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KEPT BY THE ASSISTANT SECRETARY,

AT THE APARTMENTS OF THE

ROYAL SOCIETY,

BY ORDER OF

THE PRESIDENT AND COUNCIL.

OBSERVANDA.

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_____ above the mean level of the sea .....97 feet.
Height of the receiver of the Rain Gauge above the court of Somerset House ..79 feet.
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METEOROLOGICAL JOURNAL FOR JANUARY AND FEBRUARY, 1839.

1839.	9 o'clock, A.M. Barometer uncorrected. Flint Glass.	9 o'clock, A.M. Barometer uncorrected. Crown Glass.	9 o'clock, A.M. Att. Ther.	3 o'clock, P.M. Barometer uncorrected. Flint Glass.	3 o'clock, P.M. Barometer uncorrected. Crown Glass.	3 o'clock, P.M. Att. Ther.	Dew Point at 9 A.M. deg. Fahr.	Diff. of Wet and Dry Bulb Thermometer.	External Thermometers. Fahrenheit. 9 A.M.	External Thermometers. Fahrenheit. 3 P.M.	External Thermometers. Self-registering. Lowest	External Thermometers. Self-registering. Highest	Rain in inches. Read off at 9 A.M.	Direction of the Wind at 9 A.M.	REMARKS.
JANUARY															
T 1	30.342	30.336	40.9	30.194	30.186	41.9	35	02.2	40.8	45.3	36.2	41.4		S	A.M. Overcast—brisk wind—remainder of the day cloudy—lt. wind.
W 2	30.050	30.044	43.7	30.058	30.052	44.6	38	03.6	45.4	46.7	40.8	49.3		W	A.M. Cloudy—light brisk wind. P.M. Fine—light clouds and wind. Evening, Cloudy.
T 3	29.944	29.938	44.7	29.828	29.822	45.6	40	02.1	45.3	47.8	44.2	46.2		SW	A.M. Fine—nearly cloudless. P.M. Cloudy—light wind. Evening, Overcast—very high wind.
F 4	29.530	29.524	46.2	29.576	29.568	46.8	41	01.7	42.0	44.7	41.9	47.2	.050	S	A.M. Ovct.—very lt. rain. P.M. Fine & cloudless. Ev. Fine & clear.
S 5	29.682	29.676	41.9	29.568	29.562	42.7	36	01.9	38.4	41.3	35.6	44.5		S	Fine—lt. clouds & wind throughout the day. Ev. Fine and starlight.
⊙ 6	29.718	29.712	39.7	29.518	29.510	39.9	31	02.4	35.7	34.2	34.2	39.0	.027	S	A.M. Overcast—light wind—rain early. P.M. Overcast—snow and rain. Evening, Heavy rain—high wind.
M 7	29.072	29.066	43.2	29.092	29.088	43.9	37	03.4	44.4	42.8	35.0	50.3	.227	S	A.M. Fine—light clouds—very high wind, as also throughout the night. P.M. Hail & rain—light wind. Ev. Fine & starlight.
T 8	29.538	29.530	40.5	29.546	29.540	40.6	32	03.0	34.7	38.8	34.8	46.3	.047	W	A.M. Fine and cloudless—light wind. P.M. Dark heavy clouds—brisk wind. Evening, Light snow.
W 9	29.716	29.712	38.8	29.916	29.908	38.6	31	02.2	34.2	34.8	33.6	39.8		NW	A.M. Fine—lt. clouds & wind—snow early. P.M. Fine—lt. clds. Ev. Cloudy.
T 10	30.274	30.268	35.0	30.210	30.202	36.7	30	00.2 *fz*	32.8	40.8	29.3	35.8		S	Fine—light clouds and wind, with sharp frost throughout the day. Evening, Overcast—thaw.
F 11	30.150	30.142	40.0	30.066	30.058	41.2	35	02.0	42.4	45.8	32.6	43.2	.027	S	Overcast—light wind throughout the day, with occasional rain, as also the evening.
S 12	30.180	30.172	44.3	30.236	30.230	46.2	41	02.2	47.7	46.7	42.0	50.0	.044	NNW	A.M. Overcast—lt. fog—deposition. P.M. Fine—lt. clds. Ev. Cloudy.
⊙13	30.020	30.014	45.8	29.960	29.956	47.0	41	02.6	49.8	50.0	42.7	50.3		SW var.	A.M. Cloudy—brisk wind. P.M. Overcast—very fine rain. Ev. Fine—starlight night.
M14	29.968	29.960	46.6	29.712	29.704	47.2	42	02.1	44.9	44.4	43.2	51.8		SW	Ovrct.—lt. wind, with occasional rain during the day. Ev. Hail & rain.
○ T 15	29.818	29.812	43.3	29.788	29.782	43.8	35	02.6	36.6	42.8	36.0	47.7	.127	W	Fine—lt. clds. & wind throughout the day. Ev. Fine—starlight night.
W16	29.944	29.940	39.9	29.900	29.894	40.3	32	01.3	35.3	37.7	33.0	43.2		W	Fine—light clouds and wind throughout the day—snow early. Evening, Fine—starlight night.
T17	30.012	30.004	36.9	30.012	30.004	37.7	28	02.1	30.7	37.3	30.6	40.0		WNW	Fine—lt. clds. & wind throughout the day. Ev. Fine—starlight night.
F18	30.172	30.164	35.9	30.136	30.128	37.7	29	01.9	29.7	36.7	29.5	38.0		W	A.M. Light fog & wind—white frost. P.M. Fine—light clouds and wind. Evening, Fine—starlight night.
S 19	29.572	29.566	38.6	29.488	29.482	40.8	35	01.9	42.9	43.6	29.7	44.0		SE	Overcast—light rain, with high wind throughout the day. Evening, Fine—starlight night.
⊙20	30.008	30.000	38.9	29.986	29.980	41.2	33	02.0	38.6	43.5	35.0	47.8	.177	SW	A.M. Fine—light clouds and wind. P.M. Overcast. Ev. Light rain.
M21	29.658	29.652	42.7	29.704	29.700	44.0	38	01.4	48.7	43.3	38.2	49.4	.175	SW	A.M. Overcast—lt. fog & rain. P.M. Heavy rain. Ev. Continued rain.
T22	30.090	30.084	40.9	30.204	30.196	41.5	33	01.9	34.7	38.6	33.7	49.2	.333	N	Fine—lt. clouds & wind throughout the day. Ev. Fine—starlight nt.
W23	30.530	30.524	38.7	30.530	30.522	39.9	33	01.9	36.2	39.7	34.6	37.4		NW	Cloudy, with brisk wind throughout the day. Evening, Overcast—light wind.
T24	30.532	30.526	38.7	30.456	30.448	40.2	32	01.9	36.2	43.4	33.7	40.4		SW	A.M. Overcast—lt. fog. P.M. Fine—lt. clds. & wind. Ev. Cloudy.
F 25	30.088	30.082	41.4	29.972	29.964	42.9	37	02.1	43.0	45.4	36.2	43.8		W var.	A.M. Overcast—light fog—brisk wind. P.M. Light rain and wind. Evening, The like.
S 26	30.156	30.150	40.8	30.204	30.196	40.9	32	01.8	35.3	37.2	34.4	47.3		N	A.M. Fine—lt. clds. & wind. P.M. Cloudy—lt. snow. Ev. Lt. snow.
⊙27	30.340	30.332	36.9	30.262	30.254	37.3	28	02.4	33.3	34.7	31.2	37.5		NE	A.M. Overcast—light snow—brisk wind. P.M. Fine—light clouds and wind. Evening, Cloudy—brisk wind.
M28	30.006	30.000	35.9	29.844	29.836	37.2	29	01.3	32.7	36.2	31.6	35.6		NW	Ovct.—lt. wind throughout the day. Ev. Snow.
● T 29	29.548	29.542	36.3	29.366	29.360	37.6	28	02.1	33.2	38.7	31.6	37.3		W	A.M. Fine—lt. clds. & wind. P.M. Cldy.—lt. wind. Ev. Snow & rain, with high wind.
W30	29.226	29.220	33.7	29.112	29.106	35.2	23	01.5 *fz*	27.7	31.3	23.7	36.0	.194	SW	A.M. Fine and cloudless—sharp frost. P.M. Cloudy—snow—sharp frost. Evening, Overcast—snow—high wind.
T 31	29.150	29.144	32.3	29.284	29.278	33.7	23	00.8 *fz*	30.5	33.4	25.5	32.3		W	A.M. Fine—light clouds—brisk wind—high wind throughout the night. P.M. Overcast—light snow. Ev. Heavy fall of snow.
MEAN.	29.904	29.898	40.1	29.862	29.855	41.1	33.5	02.0	38.2	40.9	34.7	43.3	Sum. 1.428		Mean Barometer corrected .... 9 A.M. 3 P.M. F. 29.877 .. 29.833 C. 29.870 .. 29.825
FEBRUARY															
F 1	30.008	30.000	33.2	30.014	30.006	34.7	25	*frozen*	29.7	35.9	26.8	33.8	.050	NW	Fine—lt. clouds—brisk wind—thaw throughout the day. Ev. Cloudy.
S 2	30.076	30.068	34.0	30.064	30.056	35.2	26	01.9	32.5	37.2	30.0	35.3	.038	NW	Fine—lt. clouds and wind throughout the day. Ev. Overcast—thaw.
⊙ 3	29.868	29.860	35.6	29.860	29.852	37.2	30	01.4	37.4	40.7	32.7	38.3	.038	S	Overcast—light rain and wind nearly the whole of the day.
M 4	29.822	29.816	37.4	29.808	29.800	39.6	32	01.3	38.7	42.8	36.6	39.3		SE	A.M. Fine—light clouds and wind. P.M. Overcast—light wind. Evening, Light rain.
T 5	30.104	30.096	41.2	30.110	30.102	41.9	34	01.7	41.8	44.7	38.3	48.8	.088	W	Overcast—deposition—light wind throughout the day. Evening, Heavy rain.
W 6	30.122	30.114	42.0	30.180	30.174	42.6	35	01.0	39.3	42.5	40.0	45.3	.377	N	Overcast—light wind throughout the day. Evening, The same.
T 7	30.288	30.282	43.8	30.276	30.268	46.2	38	01.8	47.8	51.0	39.9	48.7		SSE	A.M. Overcast—very fine rain. P.M. Lightly overcast. Evening, Overcast—light wind.
F 8	30.360	30.352	48.3	30.308	30.302	49.7	46	01.9	48.6	50.4	47.9	49.4		S	Overcast—light wind throughout the day. Evening, The same, with high wind.
S 9	30.342	30.334	50.0	30.304	30.296	51.3	44	01.9	50.7	52.3	47.9	51.8		SW	Overcast—brisk wind throughout the day.
⊙10	30.476	30.468	49.6	30.482	30.478	50.0	40	01.9	43.8	46.4	43.9	44.0	.091	NW	A.M. Fine—light clouds and wind—rain early. P.M. Lightly overcast. Evening, Fine—starlight night.
M11	30.462	30.454	45.6	30.376	30.370	46.9	40	01.3	41.4	48.3	37.9	42.0		S	Overcast—very light wind and rain nearly the whole of the day. Evening, Fine—starlight night.
T 12	30.300	30.296	47.0	30.230	30.222	47.5	41	02.5	45.9	47.7	41.2	48.8		S	Overcast—brisk wind throughout the day. Evening, Light rain.
W13	30.488	30.482	45.9	30.444	30.436	46.9	40	01.8	40.7	46.7	38.2	48.8	.061	SW	Fine—light clouds and wind throughout the day. Evening, Overcast—light wind.
○ T 14	29.910	29.904	45.9	29.946	29.940	48.2	40	02.5	48.0	50.7	40.6	48.7		S	A.M. Overcast—brisk wind. P.M. Cloudy—brisk wind. Ev. Fine and starlight.
F 15	30.104	30.098	45.3	30.034	30.028	46.9	37	01.9	39.3	48.8	36.4	52.3		SW var.	A.M. Fine—nearly cloudless—light wind. P.M. Cloudy—light wind. Evening, Light rain—high wind.
S 16	29.520	29.512	46.0	29.540	29.534	46.8	41	02.3	43.3	44.2	39.3	49.2	.055	NW	A.M. Overcast—steady rain—high wind. P.M. Fine—light clouds and wind. Evening, Fine and starlight—sharp frost.
⊙17	29.494	29.488	42 8	29.424	29.420	44.2	32	01.4	35.8	40.0	34.2	45.0		S	A.M. Fine—nearly cloudless. P.M. Overcast—snow and hail—brisk wind. Evening, The same.
M18	29.464	29.456	40.9	29.538	29.532	41.4	35	01.8	37.3	36.7	34.2	37.8	.055	S	Overcast—light wind throughout the day. Ev. Fine and starlight—sharp frost.
T 19	29.590	29.586	38.3	29.500	29.492	40.0	29	02.0	32.8	39.3	30.5	38.3	.033	NW	A.M. Overcast—lt. fog & wind. P.M. Cloudy—lt. wind. Ev. Overcast.
W20	29.374	29.368	39.4	29.498	29.492	39.8	33	02.0	38.3	39.4	32.4	39.6		NE	Overcast—light brisk wind throughout the day, as also the evening.
T 21	30.238	30.232	38.2	30.252	30.244	39.8	23	04.4	35.9	38.7	35.0	39.8		NE	Cloudy—light brisk wind throughout the day. Evening, Overcast—Snow and rain.
F 22	29.836	29.830	39.7	29.794	29.788	41.7	36	02.2	42.4	47.8	34.9	43.3	.116	S	A.M. Overcast—light wind (rain early). P.M. Overcast—light rain. Evening, The like.
S 23	29.544	29.538	45.7	29.658	29.652	47.6	40	01.7	49.8	48.7	43.0	50.9	.283	S var.	A.M. Overcast—light rain and wind. P.M. Fine—light clouds. Evening, Fine and clear.
⊙24	29.810	29.804	43.7	29.734	29.730	45.0	35	02.1	38.6	45.6	35.4	51.3		W	Fine—light clouds and wind throughout the day. Ev. The same.
M25	29.672	29.664	42.7	29.764	29.760	43.8	35	02.8	38.8	38.8	36.3	47.6		W	A.M. Fine—light clouds—brisk wind. P.M. Overcast—light rain. Evening, Fine and clear.
T 26	30.028	30.022	40.4	29.992	29.984	41.6	32	02.0	35.2	42.3	33.7	44.8	.052	W	A.M. Lt. fog & wind. P.M. Lightly overcast—lt. wind. Ev. Cloudy.
W27	29.866	29.858	40.7	29.810	29.804	41.8	33	02.5	41.2	47.3	35.2	42.4		S	A.M. Cloudy—brisk wind. P.M. Overcast—hail and rain. Evening, Fine and clear.
● T 28	30.176	30.168	40.7	30.158	30.150	42.3	32	02.6	39.3	48.4	35.7	46.5		SW	Fine—light clouds and wind throughout the day. Ev. Fine and clear.
MEAN.	29.977	29.970	42.3	29.968	29.961	43.6	35.0	02.0	40.5	44.4	37.1	44.7	Sum. 1.337		Mean Barometer corrected .... 9 A.M. 3 P.M. F. 29.943 .. 29.931 C. 29.935 .. 29.924

METEOROLOGICAL JOURNAL FOR MARCH AND APRIL, 1839.

1839.	9 o'clock, A.M. Barometer uncorrected. Flint Glass.	9 o'clock, A.M. Barometer uncorrected. Crown Glass.	9 o'clock, A.M. Att. Ther.	3 o'clock, P.M. Barometer uncorrected. Flint Glass.	3 o'clock, P.M. Barometer uncorrected. Crown Glass.	3 o'clock, P.M. Att. Ther.	Dew Point at 9 A.M., deg. Fahr.	Diff. of Wet and Dry Bulb Ther.	External Thermometers. Fahrenheit. 9 A.M.	Fahrenheit. 3 P.M.	Self-registering. Lowest	Self-registering. Highest	Rain in inches. Read off at 9 A.M.	Direction of the Wind at 9 A.M.	REMARKS.
MARCH															
F 1	30.030	30.022	44.3	29.944	29.938	45.9	39	03.1	46.3	46.2	39.7	47.7	.041	E	A.M. Lightly overcast—rain during the night. P.M. Cloudy—brisk wind. Evening, The same.
S 2	29.868	29.862	44.7	29.910	29.904	41.9	39	03.4	45.7	52.8	42.8	46.3		SSE	Fine—light clouds and wind throughout the day.
⊙ 3	30.068	30.060	45.9	30.054	30.050	48.0	40	01.8	43.7	50.7	41.6	53.3		N	A.M. Cloudy—light fog and wind. P.M. Fine—light clouds. Evening, The same.
M 4	30.052	30.044	43.7	30.044	30.036	44.9	36	02.4	40.3	41.6	36.8	50.3		NE	Fine—light clouds—high wind throughout the day. Ev. Sharp frost.
T 5	30.108	30.100	40.2	30.068	30.060	39.8	32	03.1	35.2	34.7	33.8	37.0		NE	Overcast—lt. brisk wind throughout the day. Ev. Cloudy—sharp frost.
W 6	29.854	29.846	38.2	29.744	29.738	38.9	29	Water frozen.	32.5	31.7	31.6	32.8		NE	A.M. Fine—light clouds—brisk wind. P.M. Overcast—snow and wind. Evening, Cloudy—light snow.
T 7	29.526	29.518	34.6	29.496	29.488	36.3	26		30.7	33.5	27.4	31.7		NW	A.M. Dark heavy clouds—brisk wind. P.M. Snow—brisk wind. Evening, Overcast—snow—high wind.
F 8	29.748	29.742	35.3	29.842	29.836	36.6	28		32.2	34.8	30.0	34.7		NW	A.M. Cloudy—snow—brisk wind. P.M. Fine—lt. clouds & wind. Ev. Fine—starlight night.
S 9	29.948	29.942	33.3	29.976	29.970	36.6	25		29.8	35.2	26.0	30.2		NNW	A.M. Cloudy—brisk wind. P.M. Fine—light clouds & wind. Ev. Fine—starlight night—sharp frost.
⊙10	30.172	30.166	32.7	30.180	30.174	35.0	23		30.5	36.0	26.5	35.8		E	Overcast—brisk wind throughout the day. Ev. Overcast—sharp frost.
M11	30.182	30.176	34.8	30.136	30.128	38.2	28		36.5	41.8	29.9	37.8		E	A.M. Fine—nearly cloudless—light wind. P.M. Cloudy—brisk wind. Evening, Fine and starlight—frost.
T12	30.074	30.066	37.7	30.050	30.044	39.7	29	02.9	35.4	42.4	32.8	36.3		NE var.	A.M. Fine and cloudless—light wind. P.M. Overcast—light rain and wind. Evening, Overcast.
W13	30.048	30.042	39.6	30.012	30.004	41.4	34	02.3	40.7	50.2	34.8	43.5	.022	NE	A.M. Overcast—lt. rain and wind. P.M. Cloudy—light wind. Ev. Overcast.
T14	30.014	30.006	42.3	30.024	30.016	45.0	36	00.8	45.7	52.6	40.7	50.2	.216	SE	A.M. Overcast—light rain and wind. P.M. Fine—light clouds and wind. Evening, Overcast—light rain.
○ F15	29.806	29.800	47.2	29.522	29.514	48.5	42	01.3	46.7	50.3	45.6	47.5	.327	S	Overcast—lt. rain & wind nearly the whole day. Ev. Dark heavy clds.
S16	29.260	29.254	48.6	29.238	29.232	50.2	43	03.5	46.8	50.2	42.3	50.8	.250	SW	Fine—lt. clouds & wind throughout the day. Ev. Overcast—lt. rain.
⊙17	29.464	29.456	46.5	29.588	29.582	46.4	36	02.1	39.8	42.3	38.0	51.2	.044	NE	Lightly overcast—lt. wind the whole of the day, as also the evening.
M18	29.880	29.872	41.3	29.916	29.908	41.3	33	02.5	35.8	37.7	34.8	41.0		NW	Overcast—brisk wind throughout the day. Ev. Very light rain.
T19	30.022	30 014	40.3	30.006	30.000	41.9	32	02.2	37.0	44.3	33.3	38.0		W	A.M. Overcast—light wind. P.M. Fine—light clouds and wind. Evening, Fine and clear.
W20	29.968	29.962	41.3	29.848	29.842	44.0	35	02.7	41.2	47.2	36.2	41.7		W	Overcast—light brisk wind throughout the day. Evening, Light rain—brisk wind.
T21	29.616	29.610	45.2	29.630	29.624	47.6	40	02.3	46.7	51.8	41.2	48.2	.077	W	Overcast—light brisk wind throughout the day, with occasional showers. Evening, Overcast.
F22	29.700	29.696	51.9	29.700	29.694	50.0	44	04.3	47.2	50.3	42.4	48.8	.016	SW	A.M. Fine—light clouds—brisk wind. P.M. Cloudy. Ev. The same.
S23	29.700	29.696	48.3	29.660	29.654	50.0	43	03.7	50.5	54.5	44.3	51.2		S	Cloudy—lt. brisk wind throughout the day. Ev. Overcast—lt. rain.
⊙24	29.682	29.674	49.8	29.666	29.662	53.0	44	03.0	47.4	53.0	46.8	48.3	.088	S	A.M. Cloudy—light wind—rain early. P.M. Fine—light clouds and wind. Evening, Fine and clear.
M25	29.648	29.644	52.2	29.636	29.628	51.2	43	04.2	47.7	48.8	41.8	49.3		S	A.M. Fine—lt. clouds & wind. P.M. Cloudy—brisk wind. Ev. Ditto.
T26	29.810	29.806	50.8	29.912	29.904	49.3	39	03.6	44.2	46.4	41.7	45.2		NE	A.M. Cloudy—light brisk wind. P.M. Fine—nearly cloudless. Evening, Cloudy—light wind.
W27	29.670	29.662	47.3	29.524	29.518	49.4	42	02.6	48.0	52.3	42.2	48.8	.044	S	A.M. Overcast—brisk wind—rain early. P.M. Cloudy—light rain. Evening, Cloudy.
T28	29.386	29.380	53.3	29.296	29.292	51.0	44	04.2	48.8	52.2	42.7	51.5	.133	S	A.M. Fine—light clouds—brisk wind. P.M. Cloudy, with showers. Evening, Overcast—light rain.
F29	29.454	29.448	48.2	29.516	29.508	48.7	42	03.0	43.7	42.7	40.3	53.2	.291	NNW	Overcast—brisk wind throughout the day. Ev. Cloudy—brisk wind.
● S30	29.762	29.756	45.7	29.784	29.778	45.8	35	04.1	41.2	41.6	35.0	45.7		ENE	A.M. Fine—light clouds—brisk wind. P.M. Cloudy—brisk wind. Evening, Overcast.
⊙31	29.612	29.604	42.7	29.544	29.540	44.8	37	02.5	41.0	45.7	37.2	43.0		E	Overcast—light wind throughout the day. Evening, Heavy rain.
MEAN.	29.811	29.804	43.5	29.789	29.783	44.6	36.1	02.9	41.3	45.0	37.4	44.2	Sum. 1.549		Mean Barometer corrected.............. 9 A.M. 3 P.M. F. 29.775 .. 29.750; C. 29.767 .. 29.743
APRIL															
M 1	29.586	29.560	44.3	29.570	29.564	45.4	38	02.8	41.7	42.8	40.7	46.3	.116	E	Overcast—brisk wind, with occasional rain throughout the day. Evening, Light rain.
T 2	29.766	29.758	42.8	29.836	29.830	42.7	36	01.6	38.8	38.3	38.9	41.0	.088	NE	Overcast—brisk wind, with occasional rain throughout the day. Evening, The like.
W 3	29.896	29.888	40.3	29.886	29.878	40.0	33	02.6	35.9	35.6	35.6	36.6		NE	Overcast—brisk wind throughout the day. Evening, The like.
T 4	29.986	29.978	38.3	29.980	29.972	39.2	30	02.9	35.5	37.2	33.9	36.0		NNE	Overcast—light brisk wind throughout the day. Evening, The like.
F 5	29.802	29.796	38.2	29.838	29.832	38.4	31	01.1	33.5	36.7	34.0	34.3	.061	NE	A.M. Overcast—heavy snow—light wind. P.M. Light rain—high wind. Evening, Overcast—brisk wind.
S 6	30.158	30.152	45.9	30.230	30.222	41.5	33	04.2	40.2	40.3	34.0	40.7	.340	NNE	A.M. Fine—light clouds—brisk wind. P.M. Cloudy—brisk wind. Evening, Fine and starlight.
⊙ 7	30.398	30.392	41.9	30.368	30.360	41.2	29	04.2	38.6	42.8	30.5	39.3		NNE	A.M. Cloudy—lt. wind. P.M. Fine—lt. clouds & wind. Ev. Fine & starlight.
M 8	30.320	30.312	45.3	30.298	30.290	41.3	32	05.4	40.3	38.4	34.8	41.4		NNE	A.M. Fine—lt. clouds and wind. P.M. Cloudy—light snow and wind. Ev. Overcast—very lt. rain.
T 9	30.352	30.346	40.2	30.348	30.340	41.2	32	03.2	38.8	41.7	35.0	39.7		NNE	A.M. Overcast—light snow and wind. P.M. Cloudy—brisk wind. Evening, Overcast—brisk wind.
W10	30.444	30.438	40.8	30.430	30.422	43.3	33	03.4	42.4	47.8	37.3	43.2	.027	NE	A.M. Cloudy—light wind—rain early. P.M. Fine—light clouds & wind. Evening, Fine & starlight.
T11	30.518	30.510	46.9	30.444	30.436	43.6	33	04.1	41.4	50.4	33.2	42.7		NNE	Fine—nearly cloudless—light wind throughout the day. Evening, Fine and starlight.
F12	30.282	30.274	42.8	30.236	30.230	45.3	37	03.2	42.6	47.2	37.2	43.3		N	A.M. Overcast—brisk wind. P.M. Cloudy—brisk wind. Ev. Overcast.
○ S13	30.272	30.264	45.0	30.250	30.242	46.9	38	04.6	44.8	47.2	41.3	45.3		N	Lightly overcast—brisk wind throughout the day. Ev. The like.
⊙14	30.232	30.224	45.7	30.202	30.196	48.0	39	03.8	45.7	51.8	43.7	46.4		W	Overcast—light wind throughout the day. Evening, The like.
M15	30.138	30.138	47.5	30.056	30.050	49.6	39	04.9	48.5	51.3	45.2	49.3		SW	A.M. Overcast—lt. brisk wind. P.M. Cldy.—brisk wind. Ev. Overcast.
T16	29.792	29.786	48.8	29.658	29.650	51.3	37	06.7	50.2	55.9	44.6	50.8		S	A.M. Overcast—light wind. P.M. Fine—light clouds and wind. Evening, Fine and starlight.
W17	29.436	29.430	53.3	29.492	29.486	52.2	42	05.8	48.4	48.5	45.5	49.4		W var.	A.M. Fine—light clouds—high wind, with occasional hail and rain. P.M. Overcast—light rain. Evening, The like.
T18	29.450	29.444	48.3	29.572	29.564	51.9	42	03.0	47.2	54.3	40.9	47.6	.205	S	A.M. Overcast—light rain—high wind. P.M. Cloudy—brisk wind. Evening, Overcast—light rain—high wind.
F19	29.662	29.654	55.9	29.794	29.786	54.6	45	05.0	51.4	56.5	40.7	52.0	.180	W	Fine—lt. clouds—brisk wind throughout the day. Ev. Fine & clear.
S20	30.082	30.076	58.7	30.082	30.074	53.2	42	06.2	49.8	51.8	40.8	50.7		W	Fine—light clouds and wind throughout the day. Ev. Fine & clear.
⊙21	30.260	30.252	53.5	30.226	30.222	53.0	40	05.9	48.7	54.5	41.3	49.5	.033	WNW	Fine—light clouds and wind nearly the whole day. Ev. Light fog.
M22	30.268	30.260	50.6	30.220	30.212	53.2	43	05.1	52.3	57.7	42.7	53.5		S	Cloudy—light wind throughout the day. Evening, Overcast.
T23	29.984	29.976	52.0	29.938	29.932	53.2	46	02.9	51.3	53.6	47.4	51.8	.155	S	Overcast—light rain and wind throughout the day. Ev. The like.
W24	30.078	30.070	51.3	30.056	30.048	52.7	41	04.7	45.8	51.3	42.3	46.4	.172	NW	Fine—light clouds and wind throughout the day. Ev. Fine & clear.
T25	30.074	30.068	58.3	30.012	30.004	51.5	38	05.3	44.6	52.2	36.9	46.0		NW	Fine—light clouds and wind throughout the day. Ev. Fine & clear.
F26	30.148	30.142	48.6	30.144	30.136	50.2	37	04.6	44.3	49.7	39.2	50.4		NNE	A.M. Overcast—light wind. P.M. Cloudy—light wind. Evening, Fine—light clouds.
S27	30.238	30.230	49.0	30.210	30.202	51.8	43	04.6	48.7	56.3	43.6	49.3		SE	A.M. Overcast—light fog and wind. P.M. Thick haze. Evening, Fine—light clouds.
● ⊙28	30.340	30.334	56.6	30.296	30.290	53.0	42	05.2	47.8	57.0	42.0	49.4		NNW	A.M. Fine—light haze and wind. P.M. Fine—light clouds. Evening, Fine and clear.
M29	30.250	30.242	52.2	30.162	30.154	53.9	43	04.5	48.8	62.8	42.6	49.9		E	A.M. Light fog. P.M. Fine—light clouds. Evening, Cloudy.
T30	30.148	30.142	61.4	30.076	30.068	56.2	45	06.5	57.3	63.2	46.7	58.7		E	Fine—light haze throughout the day. Evening, Fine and clear.
MEAN.	30.078	30.071	48.1	30.064	30.056	48.0	37.9	04.3	44.8	49.2	39.7	46.0	Sum. 1.377		Mean Barometer corrected .... 9 A.M. 3 P.M. F. 30.030 .. 30.016; C. 30.022 .. 30.007

On passing through Smithfield on Friday evening, the 26th of April last, between the hours of six and seven o'clock, my attention was arrested by a black spot, of the size of a crown piece, nearly in the centre of the sun, and which I watched with the naked eye for upwards of twenty minutes. There being a great quantity of vapour in the atmosphere at the time, permitted the eye to look at it with impunity.—J. D. R.

METEOROLOGICAL JOURNAL FOR MAY AND JUNE, 1839.

1839.	9 o'clock, A.M.			3 o'clock, P.M.			Dew Point at 9 A.M., deg. Fahr.	Diff. of Wet and Dry Bulb Thermometer.	External Thermometers.				Rain in inches. Read off at 9 A.M.	Direction of the Wind at 9 A.M.	REMARKS.
	Barometer uncorrected.		Att. Ther.	Barometer uncorrected.		Att. Ther.			Fahrenheit.		Self-registering				
	Flint Glass	Crown Glass.		Flint Glass.	Crown Glass.				9 A.M.	3 P.M.	Lowest	Highest			
MAY															
W 1	29.986	29.978	55.3	29.912	29.904	57.6	48	05.0	56.0	65.3	51.8	61.2		SW	A.M. Thick fog. P.M. Fine—light clouds. Evening, Cloudy.
T 2	29.948	29.944	60.9	29.918	29.910	60.2	49	07.0	60.4	66.3	51.6	64.2		NW	A.M. Cloudy—light wind. P.M. Fine—light clouds and wind. Evening, Fine and clear.
F 3	29.976	29.970	61.4	29.924	29.916	60.2	51	05.6	53.6	63.5	45.8	66.3		NNW	A.M. Lightly cloudy—light wind. P.M. Fine—light clouds and wind. Evening, Overcast.
S 4	29.832	29.824	62.8	29.728	29.720	61.3	50	06.9	59.3	66.8	51.0	61.6		E	A.M. Fine—lt. haze & wind. P.M. Fine—lt. clouds. Ev. Overcast.
⊙ 5	29.686	29.682	66.9	29.690	29.686	62.2	52	08.0	57.4	66.3	51.9	66.7		S	Fine—light clouds and wind throughout the day. Ev. Fine & clear.
M 6	29.946	29.940	62.0	29.956	29.950	61.4	51	07.5	59.7	63.7	46.0	66.7		NE	Ditto ditto. Ev. Overcast—light wind.
T 7	30.066	30.060	66.3	30.002	29.994	59.9	47	07.2	55.4	63.7	43.2	63.2		NE	Fine—nearly cloudless—light wind throughout the day. Evening, Fine and clear.
W 8	29.894	29.886	59.8	29.846	29.838	60.2	48	06.8	57.9	68.7	43.7	61.3		NE	Fine and cloudless—light brisk wind throughout the day. Evening, Overcast—thunder and lightning, with heavy rain.
T 9	29.872	29.866	60.4	29.836	29.830	58.0	47	03.2	47.2	50.7	46.3	67.4	.338	NNE	Overcast—occasional showers—brisk wind throughout the day. Evening, Heavy rain—high wind.
F 10	29.864	29.856	50.3	29.904	29.896	53.7	43	04.4	45.4	51.6	41.0	51.9	.422	N	A.M. Ovct.—brisk wind. P.M. Cloudy—brisk wind. Ev. The same.
S 11	30.160	30.152	59.6	30.120	30.114	53.3	42	06.6	47.7	53.2	42.2	51.4	.033	N	Fine—light clouds—brisk wind throughout the day. Ev. Overcast.
⊙ 12	30.044	30.036	54.7	30.028	30.022	52.0	42	06.8	48.3	47.5	41.3	51.3		NW	A.M. Cloudy—brisk wind. P.M. Overcast—light rain—brisk wind. Evening, The same.
○ M 13	29.920	29.914	54.7	29.736	29.730	53.3	42	06.6	49.2	59.5	42.3	58.8	.068	NW	A.M. Fine—light clouds and wind. P.M. Cloudy—brisk wind. Evening, Overcast—light rain.
T 14	29.548	29.540	47.8	29.478	29.472	50.3	39	03.0	39.2	47.4	36.2	50.7	.172	NW	A.M. Overcast—light rain—brisk wind. P.M. Fine—light clouds—brisk wind. Evening, Hail and light rain.
W 15	29.386	29.382	53.5	29.338	29.332	49.7	38	05.9	45.2	9.6	35.4	56.8	.016	SE	A.M. Cloudy—brisk wind. P.M. Snow, hail, & rain—brisk wind. Ev. Fine & clear.
T 16	29.556	29.550	58.2	29.526	29.518	50.8	35	06.7	46.4	53.0	33.7	63.4	.166	S	Fine—light clouds—brisk wind throughout the day. Ev. Fine & clear.
F 17	30.020	30.016	56.3	30.034	30.026	51.9	37	08.0	50.2	56.8	39.0	59.8		S	Fine—light clouds and wind throughout the day. Ev. Fine & clear.
S 18	30.124	30.118	64.9	30.068	30.060	55.2	42	08.2	53.7	58.8	42.8	69.6		S	A.M. Fine—light clouds—brisk wind. P.M. Fine—nearly cloudless—brisk wind. Evening, Overcast.
⊙ 19	30.066	30.058	53.9	30.100	30.096	57.0	48	03.7	53.7	62.0	52.2	54.3	.038	S	Overcast—deposition—light wind throughout the day. Ev. The same.
M 20	30.248	30.240	57.4	30.236	30.228	58.7	47	05.7	60.3	66.4	52.3	61.2		S	Overcast—light wind throughout the day. Evening, The same.
T 21	30.188	30.180	58.8	30.102	30.096	61.3	49	07.7	58.2	63.3	55.0	66.5		NW	Cloudy—light wind throughout the day. Ev. Fine—lt. clouds & wind.
W 22	30.004	29.996	64.3	30.046	30.040	58.6	45	07.0	50.5	49.8	47.4	65.3		NW	A.M. Dark heavy clouds, with occasional rain. P.M. Cloudy—light wind. Evening, Fine—light clouds.
T 23	30.156	30.150	61.9	30.024	30.016	57.3	43	08.4	49.8	59.0	41.6	58.0	.022	NW	Fine—light clouds—brisk wind throughout the day. Evening, Cloudy—very light rain.
F 24	29.946	29.938	58.7	30.000	29.992	56.2	43	07.0	50.3	49.8	45.2	51.7		NW	Cloudy—brisk wind throughout the day. Evening, The same.
S 25	30.120	30.114	58.9	30.138	30.132	53.8	42	07.2	47.7	50.8	41.7	52.0		N	A.M. Fine—light clouds—brisk wind. P.M. Lightly overcast—brisk wind. Evening, Fine and clear.
⊙ 26	30.216	30.210	63.9	30.184	30.180	54.4	41	05.7	48.3	58.5	40.7	60.3		NE	Fine—light clouds and wind throughout the day. Ev. Fine & clear.
M 27	30.230	30.222	59.3	30.198	30.190	56.6	43	08.1	56.3	63.8	45.0	72.2		S	Fine—nearly cloudless—light wind throughout the day. Evening, Fine—light clouds.
● T 28	30.250	30.242	62.7	30.232	30.224	58.9	50	06.8	55.5	58.4	47.2	66.0		E	Fine—light clouds and wind throughout the day. Ev. Overcast.
W 29	30.212	30.204	54.3	30.142	30.136	57.9	45	04.6	49.4	66.0	41.6	50.3		NW	A.M. Cloudy—light wind. P.M. Fine and cloudless—light wind. Evening, Fine and clear.
T 30	30.090	30.082	56.0	30.032	30.024	60.5	50	03.3	53.8	68.9	48.0	54.5		N	A.M. Overcast—brisk wind. P.M. Fine—light clouds and wind. Evening, Cloudy—light wind.
F 31	30.008	30.000	59.2	29.964	29.958	61.8	54	03.7	56.3	65.3	52.2	70.2		NW	A.M. Overcast—brisk wind. P.M. Fine—nearly cloudless.
MEAN.	29.986	29.979	58.9	29.917	29.911	56.9	45.3	06.2	52.3	58.9	45.0	60.5	Sum. 1.275		Mean Barometer corrected .... 9 A.M. 3 P.M. F 29.909 .. 29.845; C. 29.901 .. 29.838
JUNE															
S 1	29.964	29.956	59.0	29.910	29.902	62.2	52	05.3	55.2	68.0	48.2	55.7		N	Fine—light clouds and wind throughout the day. Evening, Cloudy.
⊙ 2	29.906	29.900	65.9	29.832	29.828	61.0	48	06.7	53.7	56.9	45.6	68.0		NE	A.M. Fine—light clouds and wind. P.M. Overcast—light wind. Evening, Overcast—light rain.
M 3	29.694	29.686	54.9	29.658	29.650	58.9	48	01.4	50.8	62.3	47.0	51.3	.227	ENE	A.M. Overcast—heavy rain during the night. P.M. Fine, with occasional showers. Evening, Overcast—light rain.
T 4	29.666	29.658	59.6	29.668	29.660	60.2	51	03.9	54.6	60.4	50.3	54.7	.069	E	Overcast—light wind throughout the day. Evening, The like.
W 5	29.826	29.830	60.9	29.856	29.850	61.2	52	06.0	59.3	67.2	53.3	61.7		N	A.M. Overcast—light breeze. P.M. Fine—light clouds. Evening, Cloudy—light rain.
T 6	29.970	29.964	75.4	29.952	29.946	64.7	55	08.6	63.9	67.4	54.2	57.9	.227	S	Fine—light clouds and wind throughout the day. Ev. Cloudy.
F 7	29.848	29.842	62.2	29.816	29.808	64.3	56	05.2	60.3	61.4	56.3	69.3	.033	E	A.M. Overcast—light steady rain. P.M. Overcast—light wind. Evening, The like.
S 8	29.898	29.892	62.9	29.864	29.856	65.5	56	07.0	63.2	68.8	55.9	63.7	.091	SE var.	A.M. Overcast—brisk wind. P.M. Fine—light clouds and wind. Evening, Cloudy.
⊙ 9	30.058	30.052	74.2	30.094	30.090	68.0	57	09.5	63 8	69.0	56.0	85.0		S	Fine—lt. clouds—brisk wind throughout the day. Ev. Fine & clear.
M 10	30.318	30.312	66.9	30.284	30.278	67.6	56	09.3	63.9	69.6	55.5	71.2		SW	Fine—light clouds and wind throughout the day. Evening, Cloudy—brisk wind.
○ T 11	30.262	30.258	70.8	30.288	30.280	67.6	59	08.4	64.7	70.3	59.4	70.0		W	Fine—light clouds—brisk wind throughout the day. Ev. The like.
W 12	30.244	30.238	74.6	30.132	30.124	69.3	59	08.7	67.3	74.3	57.8	80.7		S	Fine—light clouds, with light brisk wind throughout the day. Evening, Fine & clear.
T 13	29.944	29.938	83.3	29.910	29.902	72.7	65	09.9	72.0	71.8	62.2	78.3		NE	A.M. Fine and cloudless—light wind. P.M. Cloudless—brisk wind. Evening, Overcast—distant thunder.
F 14	29.866	29.858	65.6	29.876	29.870	65.9	57	02.9	58.2	62.0	55.3	77.6		NE	Overcast—brisk wind throughout the day. Evening, Cloudy.
S 15	29.946	29.940	63.7	30.046	30.038	64.9	58	02.8	58.4	61.6	55.7	64.4		NNW	Lightly overcast—light breeze throughout the day. Ev. Cloudy.
⊙ 16	30.268	30.262	75.6	30.264	30.260	66.9	53	08.0	61.3	70.2	49.0	65.0		NE	Fine & cloudless—lt. breeze throughout the day. Ev. Fine & clear.
M 17	30.200	30.192	66.0	30.154	30.148	67.8	58	06.8	64.2	69.3	52.5	70.3		ENE	Fine—nearly cloudless—light breeze throughout the day. Evening, Lightning, with rain.
T 18	30.054	30.050	75.2	29.962	29.954	71.3	65	07.7	70.6	77.6	61.6	83.6		E	A.M. Fine—light clouds and wind. P.M. Fine—light clouds—at ½ p. 4 o'clock, thunder with heavy rain. Ev. Cloudy—much lightning.
W 19	29 998	29.992	74.4	30.060	30.054	71.3	62	07.2	66.6	71.4	62.0	82.3	.050	S	A.M. Cloudy—lt. wind—thunder early. P.M. Fine—lt. clouds—brisk wind. Ev. Fine & clear.
T 20	30.158	30.152	78.9	30.038	30.030	71.8	62	08.0	67.8	75,7	58.5	85.0		S	A.M. Cloudy—light breeze. P.M. Fine—light clouds. Ev. Cloudy—very lt. rain.
F 21	29.818	29.814	78.6	29.822	29.816	71.2	62	08.2	68.3	70.7	61.0	76.2	.033	S	A.M. Fine—light clouds and wind—very high wind early. P.M. Cloudy—brisk wind. Evening, Fine and clear.
S 22	29.644	29.640	67.8	29 460	29.452	66.9	60	07.1	63.9	61.7	59.9	73.6		S	A.M. Cloudy—high wind—very light rain early. P.M. Overcast—high wind—light rain. Evening, Fine—light clouds.
⊙ 23	29.456	29.450	72.9	29.572	29.566	67.3	57	08.0	62.8	62.6	56.8	70.0	.111	SE var.	A.M. Cloudy—very high wind. P.M. Cloudy—light rain—high wind Ev. Dark heavy clouds—high wind, with light showers.
M 24	29.842	29.836	71.9	29.870	29.862	67.9	58	08.1	63.4	68.3	55.6	76.4	.319	S	A.M. Cloudy—light wind. P.M. Fine—light clouds. Ev. The like.
T 25	29.968	29.962	68.8	29.918	29.912	67.3	57	07.9	64.3	69.8	57.4	69.3		S	Fine—light clouds and wind throughout the day. Evening, Overcast—light wind.
● W 26	29.552	29.546	66.8	29.476	29.470	66.7	58	06.3	63.4	67.0	56.0	70.4		E	A.M. Cloudy—thunder—light rain—high wind. P.M. Continued. Evening, Overcast—light rain.
T 27	29.892	29.888	73.0	29.846	29.840	66.8	57	08.5	62.8	66.7	54.2	68.6	.083	W	Fine—lt. clouds—brisk wind throughout the day. Ev. Ovct.—lt. rain.
F 28	29.684	29.680	70.3	29.706	29.702	64.6	57	07.5	61.3	58.3	54.7	81.2	.133	S	A.M. Fine—light clouds, and with occasional rain. P.M. Overcast—light rain—brisk wind. Evening, The like.
S 29	29.956	29.950	59.9	30.038	30.032	61.7	52	04.3	53.7	59.2	50.3	54.0	.144	WNW	Overcast—light wind throughout the day. Evening, The like.
⊙ 30	30.158	30.150	60.9	30.204	30.200	59.5	46	06.7	53.3	54.0	45.8	53.8		W	Cloudy—light wind throughout the day. Evening, The like.
MEAN.	29.936	29.930	68.7	29.919	29.913	66.1	56.4	06.9	61.9	66.3	54.9	70.2	Sum. 1.520		Mean Barometer corrected .... 9 A.M. 3 P.M. F. 29.832 .. 29.823; C. 29.825 .. 29.816

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OF

THE ROYAL SOCIETY.

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JOHN TAYLOR, ESQ.

*** *This Council will continue till November* 30, 1840.

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5. MINERALOGY AND GEOLOGY.

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6. BOTANY AND VEGETABLE PHYSIOLOGY.

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MR. STOKES.
MR. H. F. TALBOT.
MR. DAWSON TURNER.
DR. WALLICH.

7. ZOOLOGY AND ANIMAL PHYSIOLOGY.

SIR BEN. BRODIE, Bart., Chairman;
MR. THOMAS BELL, Secretary.

SIR CHARLES BELL.
DR. BOSTOCK.
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MR. LAWRENCE.
MR. MACLEAY.
MR. HERBERT MAYO.
MR. OWEN.
DR. WILSON PHILIP.
DR. PRICHARD.
DR. ROGET.
DR. TODD.

By a resolution of the Council (April 11th, 1839,) the President, Treasurer, and Secretaries are *ex-officio* Members of all Committees.

THE ROYAL SOCIETY.

30th November 1839.

THE ROYAL SOCIETY. Nov. 30, 1839.

Her Sacred Majesty QUEEN VICTORIA, Patroness.

Date of Election.	
1828. Apr. 24.	HIS ROYAL HIGHNESS ERNEST AUGUSTUS, DUKE OF CUMBERLAND, KING OF HANOVER.
1828. May 22.	HIS ROYAL HIGHNESS AUGUSTUS FREDERICK, DUKE OF SUSSEX.
1817.	HIS IMPERIAL MAJESTY NICHOLAS EMPEROR OF ALL THE RUSSIAS.
1816.	HIS MAJESTY LEOPOLD KING OF THE BELGIANS.
1822. June 6.	HIS ROYAL HIGHNESS CHRISTIAN FREDERICK, HEREDITARY PRINCE OF DENMARK.
1838. May 24.	HIS IMPERIAL AND ROYAL HIGHNESS LEOPOLD THE SECOND, GRAND DUKE OF TUSCANY.
1826. Dec. 21.	HIS ROYAL HIGHNESS JOSEPH FRANCIS OSCAR, CROWN PRINCE OF SWEDEN AND NORWAY.
1816. Feb. 8.	HIS IMPERIAL HIGHNESS THE ARCHDUKE JOHN OF AUSTRIA.
1816. Feb. 8.	HIS IMPERIAL HIGHNESS THE ARCHDUKE LOUIS OF AUSTRIA.
1802. Mar. 4.	HIS IMPERIAL HIGHNESS THE ARCHDUKE MAXIMILIAN OF AUSTRIA.

FELLOWS OF THE SOCIETY.

NOVEMBER 30, 1839.

(*) prefixed to a name indicates that the Member is liable to an annual payment of £2 12 0.
(†) prefixed to a name indicates that the Member is liable to an annual payment of £4.

Date of Election.	
1808. Apr. 28.	Aberdeen, George Earl of, K.T. Trust. Brit. Mus.—President of the Society of Antiquaries. *Argyll-house.*
1839. June 20.	Acland, Sir Thomas Dyke, Bart., M.P., F.G.S.
1834. Apr. 10.	Adare, Edwin Viscount. M.P., F.R.A.S. *Adare Abbey, Limerick; Dunraven Castle, Glamorganshire.*
1832. June 7.	† Agar, Hon. George Charles, M.A. *University Club.*
1819. Feb. 18.	Ailsa, Archibald Marquess of, K.T. *Whitehall-gardens; and Culzean-castle, Ayrshire.*
1836. Jan. 21.	Airy, George Biddell, Esq., M.A., Astronomer Royal. V.P.R.A.S.—Inst. Reg. Sc. Paris. Corresp. *The Observatory, Greenwich.*
1835. Nov. 26.	† Alexander, Robert, Esq. F.S.A. 13 *Duke-street, Westminster.*
1807. Nov. 19.	Allen, William, Esq. F.L.S. F.G.S. F.R.A.S. *Plough-court, Lombard-street; and Paradise-row, Stoke Newington.*
1824. Jan. 22.	Amyot, Thomas, Esq. Treas. S.A. M.R.I.A. Soc. Reg. Sc. Hafn. Socius. 13 *James-street, Westminster.*
1811. May 23.	Anderdon, John Proctor, Esq.
1821. Mar. 29.	Andrew, James, LL.D.
1834. Apr. 10.	Ansell, Charles, Esq. *Tottenham.*
1786. Jan. 19.	Arden, Charles George Lord, F.S.A. 26 *St. James's-place.*
1819. May 20.	Argyll, John Douglas Edward Henry Campbell, Duke of, F.R.S.E.
1838. Jan. 25.	† Arnott, Neil, M.D. 38 *Bedford-square.*
1830. Mar. 18.	Audubon, John James, Esq.
1837. June 1.	† Ayrton, William, Esq. F.S.A. 4 *James-street, Buckingham-gate.*
1816. Mar. 14.	Babbage, Charles, Esq. M.A. F.R.S.E. M.R.I.A. F.R.A.S. M.C.P.S. Acadd. Reg. Sc. Masil., Hafn., et Divion. ex intim.: Acad. Amer. Art. et Sc. Bost., Socc. Reg. Œcon. Boruss., et Phys. Hist. Nat. Genev., Socius.—Acadd. Imp. et Reg. Petrop. Pat., Georg. Florent., Brux., Neap., Mut., Lync. Rom., Societ. Philomat. Paris., Corresp. 1 *Dorset-street, Manchester-square.*
1816. May 23.	* Baber, Rev. Henry Hervey, M.A. M.R.S.L. Acad. Reg. Sc. Monach. Socius. *Stretham, Cambridgeshire.*
1828. Mar. 13.	Babington, Benjamin Guy, M.D. *George-street, Hanover-square.*
1836. Feb. 11.	† Baillie, David, Esq. 4 *Audley-square.*
1821. Feb. 22.	Baily, Francis, Esq. D.C.L.—Vice-President.—M.R.I.A. F.L.S. F.G.S.—V.P.R.A.S.—Instit. Reg. Sc. Paris. Corresp.—Acadd. Reg. Sc. Neap., et Sc. et Lit. Panorm., Corresp.—Acad. Amer. Art. et Sc. Bost. Socius. 37 *Tavistock-place, Russell-square; and East Tytherley, in Hampshire.*

Date of Election.	
1828. Dec. 11.	† Baird, Andrew, M.D. 2 *Clarges-street, Piccadilly.*
1822. Mar. 28.	Bankes, William John, Esq. 5 *Old Palace-yard, Westminster; and Soughton-hall near Northupt, Flintshire, North Wales.*
1839. June 6.	† Barker, George, Esq. *Birmingham.*
1834. Dec. 18.	Barlow, Rev. John, M.A. F.L.S. 22 *Henrietta-street, Cavendish-square.*
1823. May 29.	Barlow, Peter, Esq. F.R.A.S. Hon. F.C.P.S. Acadd. Imp. Sc. Petrop., Amer. Art. et Sc. Bost. Socius.—Instit. Reg. Sc. Paris., et Acad. Reg. Sc. Brux. Corresp. *Royal Military Academy, Woolwich.*
1819. Jan. 21.	Barlow, Rear-Admiral Sir Robert, K.C.B. *Canterbury.*
1818. Nov. 12.	Barnewell, Rev. Frederick Henry, M.A. F.S.A. *Bury St. Edmunds.*
1809. Mar. 9.	Barnwell, Charles Frederick, Esq. M.A. F.S.A. 44 *Woburn-place, Russell-square.*
1823. Feb. 13.	Baron, John, M.D. *Gloucester.*
1805. July 4.	Barrow, Sir John, Bart.—VICE-PRESIDENT.—F.L.S. 21 *New-street, Spring-gardens.*
1838. Feb. 8.	† Bateman, James, Esq. F.L.S. F.R.G.S. F.H.S. *Knypersley-hall, Staffordshire.*
1814. Feb. 14.	* Bath and Wells, George Henry Law, Lord Bishop of. F.S.A. 4 *Langham-place; and Wells, Somersetshire.*
1822. Feb. 28.	Batty, Lieut.-Colonel Robert.
1821. Feb. 8.	Bauer, Francis, Esq. F.L.S. *Kew Green.*
1828. Feb. 21.	† Baylay, Rev. William Frederick, M.A. F.S.A *Canterbury.*
1827. Nov. 15.	Beamish, Major North Ludlow. *Windham Club, St. James's-square.*
1836. Mar. 24.	Beamish, Richard, Esq. *Manor House, Princes, Risborough, Bucks.*
1818. Apr. 30.	Beatty, Sir William, Knt. M.D. F.L.S. *Royal Hospital, Greenwich.*
1809. Dec. 7.	Beauclerk, Vice-Admiral Lord Amelius, K.C.B. G.C.H. *Plymouth.*
1814. June 30.	Beaufort, Francis, Esq. Captain in the Royal Navy, F.G.S. F.R.A.S. Instit. Sc. Paris. Corresp. *Admiralty; and* 11 *Gloucester-place, Portman-square.*
1815. Dec. 14.	Beaufoy, Henry, Esq. F.L.S. *South Lambeth.*
1835. June 4.	† Beaumont, Edward Blackett, Esq. F.R.A.S. *Finningly-park, near Bawtry, Yorkshire.*
1816. Mar. 14.	Beckett, Right Hon. Sir John, Bart. LL.D. 11 *Stratford-place; and Somerby-park, Gainsborough.*
1824. Dec. 23.	† Beechey, Frederick William, Esq. Captain in the Royal Navy, F.R.A.S. *Worthing.*
1835. Feb. 5.	† Beetham, Albert William, Esq. F.L.S. *Forest-lodge, Tulse-hill, Surrey.*
1826. Nov. 16.	Bell, Sir Charles, K.H. F.R.S.E. F.L.S. F.G.S. Professor of Surgery. *Edinburgh.*
1828. Jan. 10.	Bell, Thomas, Esq. F.L.S. Prof. of Zoology, King's College, London. 17 *New Broad-street.*
1834. Dec. 18.	† Bellamy, Rev. James William, B.D. *Merchant Tailors' School, Suffolk-lane.*
1831. May 5.	Beverly, Charles James, Esq. 1 *Hackney-grove, Hackney.*
1822. Feb. 7.	Bexley, Nicholas Lord, M.A. F.S.A. M.R.S.L. 31 *Great George-street; and Foot's Cray-place, Kent.*
1827. May 10.	Bicheno, James Ebenezer, Esq. F.L.S. F.G.S. *Ty-Maen, near Pyle, Glamorganshire.*
1821. Mar. 8.	Bicknell, John Laurens, Esq. 25 *Abingdon-street.*
1837. June 8.	† Bigsby, Robert Grymbald, Esq. F.S.A.
1809. June 22.	Bingley, Robert, Esq. F.G.S. *Royal Mint, Tower-hill; and Woodford, Essex.*
1830. Mar. 4.	Blake, Captain Benjamin, F.G.S. F.R.A.S. *India.*
1807. May 14.	Blake, William, Esq. M.A. F.G.S. 62 *Portland-place; and Danesbury, near Welwyn, Hertfordshire.*
1831. Jan. 20.	Blake, William John, Esq. 62 *Portland-place.*

Date of Election.	
1816. Feb. 8.	Bland, Michael, Esq. F.S.A. F.L.S. F.G.S. *St. Leonard's, Hastings.*
1821. Apr. 12.	Bland, Rev. Miles, D.D. F.S.A. F.R.A.S. M.R.S.L. *Ramsgate.*
1803. Mar. 10.	Blizard, Thomas, Esq. F.R.S.E. *Lillay Rectory, near Luton.*
1837. May 11.	Boase, Henry, M.D. F.G.S. *Claverhouse, near Dundee.*
1834. Apr. 10.	† Booth, Sir Felix, Bart. 43 *Portland-place; and Hendon, Middlesex.*
1828. Nov. 20.	Borlase, George Simon, Esq. *Helston, Cornwall.*
1835. June 4.	† Borrer, William, Esq. F.L.S. *Henfield, Sussex.*
1793. June 6.	Bosanquet, Samuel, Esq. 78 *Lombard-street.*
1818. Apr. 2.	Bostock, John, M.D. F.L.S. F.G.S. F.R.A.S. 22 *Upper Bedford-place.*
1829. June 4.	Bosworth, Rev. Joseph, LL.D. F.S.A. M.R.S.L. Socc. Reg. Sc. Norv., Dronth., et Gothenb., Socius. *British Chaplain, Rotterdam.*
1839. Jan. 17.	Botfield, Beriah, Esq. *Norton-hall, Northamptonshire.*
1833. Apr. 18.	† Botfield, Thomas, Esq. F.G.S. *Hopton-court, Bewdley.*
1814. May 5.	Boughton, Sir William Edward Rouse, Bart. *Downton-hall, Ludlow.*
1826. Apr. 20.	Bourne, Right Hon. William Sturges, M.A. 37 *Brook-street; and Testwood-house, Southampton.*
1814. June 23.	Boyle, Hon. Sir Courtenay, Knt. 24 *Upper Berkeley-street; and Hampton-court Palace.*
1809. Apr. 13.	Brande, William Thomas, Esq., Professor of Chemistry in the Royal Institution. F.R.S.E. F.G.S. *Royal Mint, Tower-hill.*
1821. Mar. 8.	Brandreth, Thomas Shaw, Esq. 18 *Bedford-square.*
1834. June 5.	† Breadalbane, John Campbell, Marquess of. 21 *Park-lane.*
1815. May 4.	Brewster, Sir David, K.H. LL.D. F.R.S.E. Hon. M.R.I.A. F.G.S. F.R.A.S. Instit. Reg. Sc. Paris. Corresp.—Soc. Reg. Sc. Gotting. Socius. *Allerly, Melrose, N.B.*
1821. Mar. 15.	Bridgman, William, Esq. F.S.A. *Frogmore, Gloucester.*
1838. Nov. 22.	† Briggs, Major-General John, E.I.C.S. M.R.A.S. F.G.S. 11 *York-gate, Regent's-park.*
1821. Mar. 8.	Bright, Richard, M.D. F.G.S. Soc. Reg. Sc. Hafn. Socius.—Acad. Sc. Sien., Socc. Erud. Hung., et Medico-Chir. Berolin., Corresp. 11 *Saville-street.*
1810. May 10.	Brisbane, Lieut.-General Sir Thomas Makdougall, K.C.B. G.C.H. D.C.L. F.R.S.E. F.R.A.S. Instit. Reg. Sc. Paris. Corresp.—President of the Royal Society of Edinburgh. *Makerstown, Kelso.*
1805. May 23.	Bristol, Frederick William, Marquess of. 6 *St. James's-square.*
1834. Dec. 18.	† Brockedon, William, Esq. 29 *Devonshire-street, Queen's-square.*
1828. Feb. 14.	Broderip, William John, Esq. B.A. F.L.S. V.P.G.S. 2 *Raymond's-buildings, Gray's-inn.*
1810. Feb. 15.	* Brodie, Sir Benjamin Collins, Bart. Serjeant Surgeon to the Queen. 14 *Saville-street.*
1817. Mar. 13.	Bromhead, Sir Edward Ffrench, Bart. M.A. F.R.S.E. F.R.A.S. *Thurlby, Lincolnshire.*
1823. May 29.	Brooke, Sir Arthur Brooke de Capell, Bart. M.A. F.L.S. F.G.S. *Oakley, Northamptonshire.*
1819. Apr. 22.	Brooke, Henry James, Esq. F.L.S. F.G.S. *Clapham-Rise.*
1803. Mar. 3.	Brougham and Vaux, Henry Lord, M.A. Instit. Reg. Sc. Paris. Socius. 4 *Grafton-street; and Brougham-hall, Penrith.*
1811. Dec. 12.	Brown, Robert, Esq. D.C.L. Hon. Mem. R.S.E., R.I.A., and C.P.S. V.P.L.S. Instit. Reg. Sc. Paris, Socius.—Acadd. Imp. Sc. Petrop., et Cæs. Nat. Cur., Reg. Sc. Berol., Holm. et Monach., Socc. Reg. Sc. Hafn. et Upsal., Instit. Reg. Sc. Amstelod., Socc. Sc. Harlem., Trajectin., Phys. et Hist. Nat. Genev., Imp. Hist. Nat. Mosc., Nat. Scrutat. Berolin., Wetter, Phil. Nov-Ebor., et Med. Holm. Socius. Acadd. Reg. Sc. Bruxell., et Bonon. Corresp. 17 *Dean-street, Soho-square.*

Date of Election.	
1838. May 8.	Brownlow, John Earl, D.C.L. F.S.A. F.L.S. F.G.S. M.R.A.S. 12 *Belgrave-square.*
1829. Mar. 18.	Bruce, James Lewis Knight, Esq. F.S.A. 1 *Old-square, Lincoln's-inn.*
1830. June 10.	Brunel, Isambard Kingdom, Esq. 30 *Bridge-street, Blackfriars.*
1814. Mar. 24.	Brunel, Mark Isambard, Esq. Instit. Reg. Sc. Paris., et Acad. Reg. Sc. Monach., Corresp. 18 *Duke-street, Westminster.*
1833. June 20.	Buccleuch, Walter Francis Duke of, K.T. D.C.L. *Whitehall-gardens; and Dalkeith-house, Edinburgh.*
1818. Feb. 26.	Buckland, Rev. William, D.D., Professor of Mineralogy and Geology, Oxford. President of the Geological Society. F.L.S. Instit. Reg. Sc. Paris. Corresp., Socc. Min. Imp. Petrop. et Cæs. Nat. Cur. Mosc., Socius. *Christ-church, Oxford.*
1836. Jan. 21.	† Budd, George, M.D. 9 *Bedford-place, Russell-square; and Caius-college, Cambridge.*
1829. Dec. 10.	Burlington, William Earl of, M.A.—Chancellor of the University of London.—F.G.S. 10 *Belgrave-square; and Hardwick-hall, Derbyshire.*
1834. Apr. 10.	Burnes, Lieut.-Colonel Sir Alexander, Knt. M.R.A.S. F.G.S. *Bombay Army, India.*
1835. Apr. 2.	Burnes, James, K.H. D.C.L. *India.*
1837. Mar. 16.	† Burnet, John, Esq. 2 *Whiteheads Grove, Chelsea.*
1838. May 3.	† Burnet, Rev. Thomas, D.D., Rector of St. James, Garlickhythe.
1833. Apr. 18.	† Burnett, Sir William, K.C.H. M.D. Coll. Reg. Med. Socius.—Acadd. Med. et Chir. Petrop. Socius Honor. 5 *Somerset-place.*
1814. Dec. 22.	Burney, Rev. Charles Parr, D.D. F.S.A. F.L.S. F.G.S. F.R.A.S. M.R.A.S. M.R.S.L. *Rectory-house, Sible Hedingham, near Halstead, Essex.*
1829. Apr. 1.	Burns, John, M.D. *Glasgow.*
1817. Apr. 24.	Burroughs, Sir William, Bart. M.R.A.S.
1818. Feb. 26.	Burrow, Rev. Edward John, D.D. F.L.S. F.G.S.
1836. Mar. 17.	Burt, Major T. Seymour, M.R.A.S. 32 *Essex-street, Strand; and India.*
1832. Dec. 6.	Burton, Decimus, Esq. 6 *Spring-gardens; and St. Leonard's, Hastings.*
1836. May 5.	† Burton, Edward, Esq. F.L.S. *Chatham.*
1818. Jan. 8	Bute, John Marquess of, D.C.L. F.R.A.S. *Camden-hill, Kensington.*
1819. May 20.	Butler, Rev. George, D.D. F.S.A. F.R.A.S.
1822. Mar. 21.	Butter, John, M.D. F.L.S. *Plymouth; and Corringdon-hall, South Brent, Devonshire.*
1837. Jan. 19.	Cabbell, Benjamin Bond, Esq. F.S.A. 1 *Brick-court, Temple.*
1810. June 28.	Cadell, William Archibald, Esq. F.R.S.E. F.G.S. *Edinburgh.*
1831. Mar. 10.	Caldcleugh, Alexander, Esq. F.L.S. F.G.S. *Chili.*
1796. Nov. 17.	Canterbury, Right Hon. William Howley, D.D., Lord Archbishop of. Trust. Brit. Mus. F.S.A. M.R.S.L. *Lambeth-palace.*
1820. Mar. 2.	Card, Rev. Henry, D.D. F.S.A. *Great Malvern, Worcestershire.*
1826. Feb. 9.	Carleton, Hon. and Rev. Richard, M.A. *Greywell-hill, Odiham, Hampshire.*
1804. Mar. 8.	Carlisle, Sir Anthony, Knt. F.S.A. F.L.S. 6 *Langham-place.*
1814. May 19.	Carlisle, Nicholas, Esq. K.H. D.C.L. M.R.I.A. Sec. S.A. Soc. Reg. Antiq. Hafn., et Acad. Reg. Sc. Holm. Socius.—Acad. Sc. et Lit. Panorm. Corresp. *Somerset-house.*
1838. May 3.	† Carnac, Sir James Rivett, Bart. *Governor of Bombay.*
1818. May 28.	Carne, Joseph, Esq. M.R.I.A. F.G.S. *Penzance.*
1817. Feb. 13.	* Carpue, Joseph Constantine, Esq. 45 *Upper Charlotte-street, Fitzroy-square.*
1839. Feb. 14.	† Carrington, Robert John Lord. *Whitehall-yard; and Wycombe-abbey, Wendover-house, Bucks.*

Date of Election.	
1800. Dec. 18.	Carrington, Sir Codrington Edmund, Knt. D.C.L. F.S.A. M.R.A.S. 32 *Russell-square.*
1837. June 1.	† Carson, James, M.D. *Liverpool.*
1812. June 11.	Cawdor, John Frederick Earl, Trust. Brit. Mus. F.G.S. 74 *South Audley-street.*
1828. Mar. 13.	Chambers, William Frederick, M.D. K.C.H. Physician to the Queen. Coll. Reg. Med. Socius. 46 *Brook-street.*
1833. Feb. 7.	† Chandler, George, Dean of Chichester. D.C.L. M.R.S.L. R.G.S. 36 *Mortimer-street.*
1818. Apr. 30.	Chantrey, Sir Francis L., K.H. R.A. D.C.L. F.R.S.E. F.S.A. M.R.S.L. 30 *Lower Belgrave-place, Pimlico.*
1816. Nov. 21.	Chapman, Colonel Sir Stephen Remnant, C.B. K.C.H. Royal Engineers. *Bermudas.*
1836. Apr. 28.	† Chapman, John James, Esq., Captain Royal Artillery. *Athenæum.*
1834. Feb. 6.	Chesney, Lt.-Colonel. F. R., Royal Artillery. 11 *Wilton-terrace, Grosvenor-place.*
1807. Mar. 12.	Children, John George, Esq. F.R.S.E. F.S.A. F.L.S. F.G.S. *British Museum.*
1826. Jan. 12.	Christie, Samuel Hunter, Esq. M.A.—SECRETARY.—F.R.A.S. Professor of Mathematics, Royal Military Academy. Acad. Sc. et Lit. Panorm., et Soc. Philom. Paris., Corresp. *Royal Military Academy.*
1818. Dec. 10.	Churchill, Lord Francis Almaric. *Cornbury-park, near Witney, Oxfordshire.*
1832. June 7.	† Churchill, Lord Henry John Spencer, Captain in the Royal Navy. F.L.S. *Kensington-palace.*
1832. June 7.	Clark, Sir James, Bart., M.D. Physician to the Queen. 21 *George-street, Hanover-square.*
1836. Jan. 28.	† Clark, William, M.D. *Cambridge.*
1837. May 11.	† Clark, William Tierney, Esq. *Hammersmith.*
1825. June 9.	Clarke, Sir Charles Mansfield, Bart. M.D. 10 *Saville-street; and Dunham-lodge, Swaffham, Norfolk.*
1820. May 18.	Clarke, Loftus Longueville, Esq. M.A. *India.*
1821. June 7.	Clarke, William Stanley, Esq. F.G.S. *East India-house; and Leatherhead, Surrey.*
1819. May 27.	Clerk, Sir George, Bart. D.C.L. M.P. F.R.S.E. F.G.S. *Penicuick-house, Edinburghshire.*
1833. Apr. 18.	† Clerke, Major T. H. Shadwell, K.H. F.R.A.S. 8 *Trevor-terrace, Knightsbridge.*
1823. May 8.	Clift, William, Esq. F.G.S. *Royal College of Surgeons, Lincoln's-inn-fields.*
1828. June 5.	† Clifton, Marshall Waller, Esq. *Boulogne.*
1820. Dec. 21.	Cockburn, Vice-Admiral Right Hon. Sir George, G.C.B. G.C.H. F.R.A.S.
1829. Feb. 12.	Coddington, Rev. Henry, M.A. F.R.A.S. *Ware, Hertfordshire.*
1822. Nov. 21.	Codrington, Vice-Admiral Sir Edward, G.C.B. 92 *Eaton-square; and Hampton-lodge, Brighton.*
1820. Apr. 13.	Colby, Lieut.-Colonel Thomas, Royal Engineers, LL.D. F.R.S.E. M.R.I.A. F.G.S. F.R.A.S. M.R.A.S. *Ordnance Map Office, Tower; and Depôt Ordnance Survey of Ireland, Dublin.*
1829. Jan. 15.	Cole, Wm. Willoughby Viscount, D.C.L. F.G.S. *Florence-court, Fermanagh, Ireland.*
1830. Feb. 18.	Collier, Charles, Esq. 20 *Fitzroy-square.*
1830. Jan. 14.	† Colquhoun, Major James Nisbet, Royal Artillery.
1839. Feb. 21.	† Conolly, Arthur, Esq. Captain in the Bengal Cavalry Service. *Bengal.*
1819. Dec. 9.	Conybeare, Rev. William Daniel, M.A. F.G.S. Instit. Reg. Sc. Paris. Corresp.
1802. Feb. 18.	Cooper, Sir Astley Paston, Bart. D.C.L., Serjeant Surgeon to the Queen. Instit. Reg. Sc. Paris., et Soc. Reg. Sc. Gotting., Corresp. 39 *Conduit-street; and Gadebridge, Hemel-Hempstead.*

Date of Election.	
1829. June 18.	Cooper, Bransby Blake, Esq. 2 *New-street, Spring-gardens.*
1832. Dec. 6.	Cooper, Charles Purton, Esq. LL.D. *New Boswell-court, Lincoln's-inn.*
1834. Feb. 6.	Copeland, Thomas, Esq. 4 *Golden-square.*
1833. Dec. 5.	† Copland, James, M.D. Coll.Reg. Med. Socius. 1 *Bulstrode-street.*
1834. Apr. 10.	† Corbaux, Francis, Esq. 59 *Upper Norton-street, Portland-place.*
1821. May 24.	Cotton, William, Esq. F.S.A. 3 *Crosby-square, Bishopsgate-street; and Walwood-house, Leytonstone.*
1836. May 5.	† Cox, William Sands, Esq. *Birmingham.*
1812. Apr. 16.	Crampton, Sir Philip Cecil, Bart. D.C.L.
1818. May 7.	Crawford, John, Esq. F.L.S. F.G.S. M.R.A.S. *Wilton-terrace, Knightsbridge.*
1823. Nov. 20.	Cresswell, Rev. Daniel, D.D. *Enfield, Middlesex.*
1800. May 8.	* Crichton, Sir Alexander, Knt. M.D. Grand Cross of St. Anne and St. Vladimir. F.L.S. F.G.S. Acad. Imp. Sc. Petrop., et Soc. Hist. Nat. Mosc., Socius.—Soc. Reg. Sc. Gotting. Corresp. *Seal Chart, near Sevenoaks, Kent.*
1818. Mar. 5.	Croft, Sir John, Bart. K.T.S. D.C.L. Acad. Reg. Olyssip. Socius. 16 *Hyde Park-street; and Cowling-hall, Yorkshire.*
1810. July 5.	Croker, Right Hon. John Wilson, LL.D. 14 *Duke-street, Westminster.*
1829. Feb. 5.	Crombie, Rev. Alexander, LL.D. M.R.S.L. 12 *York-terrace, Regent's-park.*
1836. Feb. 18.	† Crosse, John Green, M.D. Acad. Reg. Med. Paris., Soc. Reg. Med. Hafn. Med. Chir. Berolin., Soc. Amer. Phis. Philad. Socius. *Norwich.*
1830. April 1.	Cubitt, William, Esq. M.R.I.A. F.R.A.S. 6 *Great George-street, Westminster.*
1807. Jan. 22.	Cuming, Lieut.-General Hon. John Leslie.
1816. Jan. 11.	Cumming, Rev. James, M.A., Professor of Chemistry, Cambridge. F.G.S. *Cambridge.*
1838. Jan. 25.	† Cureton, Rev. William, M.A. 31 a *Bedford-square; and British Museum.*
1834. Feb. 6.	† Cust, Hon. Sir Edward, K.C.H. *New-street, Spring-gardens.*
1822. Mar. 7.	Dalton, John, Esq. D.C.L. Instit. Reg. Sc. Paris., et Acad. Reg. Sc. Monach., Socius. *Philosophical Society, Manchester.*
1828. June 5.	† Daniell, Edmund Robert, Esq. Sec. R.I. 57 *Russell-square.*
1814. May 5.	* Daniell, John Frederic, Esq.—Foreign Secretary.—Professor of Chemistry, King's-college, London. *Norwood.*
1822. Nov. 7.	Dartmouth, William Earl of, D.C.L. F.S.A. 1 *St. James's-square.*
1839. Jan. 24.	Darwin, Charles, Esq. M.A. Sec. G.S. 12 *Upper Gower-street.*
1788. Feb. 21.	Darwin, Robert Waring, M.D. *Shrewsbury.*
1822. Dec. 19.	Daubeny, Charles Giles Bridle, M.D., Aldrich's Professor of Chemistry, Regius Professor of Botany, Oxford. F.L.S. F.G.S. Coll. Reg. Med. Socius. *Oxford.*
1839. May 30.	† Davenport, Edward Davies, Esq. *Upper Brook-street.*
1831. June 16.	Davies, Griffith, Esq. *Palmer-terrace, Islington.*
1833. Apr. 18.	Davies, Thomas Stephens, Esq. F.R.S.E. F.R.A.S. *Royal Military Academy, Woolwich.*
1822. Mar. 28.	Davis, John Francis, Esq. 73 *Portland-place.*
1812. Apr. 23.	Davis, Richard Hart, Esq.
1826. Jan. 19.	Davy, Edmund, Esq., Professor of Chemistry to the Royal Dublin Society. M.R.I.A. *Dublin.*
1814. Feb. 17.	Davy, John, M.D. *Fort Pitt, Chatham.*
1815. Mar. 9.	Dawkins, Colyer James, Esq. F.S.A. *Ham-common, Richmond.*
1811. Feb. 28.	Dealtry, Rev. William, D.D. F.R.A.S. *Clapham-common.*

Date of Election.	
1819. Dec. 23.	De la Beche, Henry T. Esq., F.L.S. F.G.S. *Ordnance Map Office, Tower.*
1835. Apr. 2.	Delafield, Joseph, Esq. F.S.A. 39 *Bryanstone-square.*
1839. Feb. 28.	† Denham, Henry Mangles, Esq. Commander in the Royal Navy. *Liverpool.*
1838. Feb. 22.	Denison, William Thomas, Esq. Lieut. in the Royal Engineers. F.R.A.S. F.R.G.S. *Dock-yard, Woolwich.*
1833. June 20.	† Denman, Thomas Lord. *Portland-place; and Stoney Middleton, Derbyshire.*
1814. Mar. 17.	Dickenson, John, Esq. F.S.A. F.G.S. 32 *Devonshire-place; and Grundisburgh-hall, Woodbridge, Suffolk.*
1804. Feb. 2.	Dillwyn, Lewis Weston, Esq. F.L.S. F.G.S. *Sketty-hall, near Swansea.*
1832. June 7.	† Disney, John, Esq. F.S.A. 18 *Berkeley-square; and The Hyde, near Ingatestone, Essex.*
1811. Mar. 21.	Dixon, Rev. Richard, M.A. *Rectory, Isle of Wight.*
1835. June 4.	† Dobson, Sir Richard, Knt. *Royal Hospital, Greenwich.*
1819. Dec. 23.	Dollond, George, Esq. F.R.A.S. 59 *St. Paul's Churchyard; and North-terrace, Camberwell.*
1838. Jan. 18.	† Donkin, Bryan, Esq. F.R.A.S. 6 *Paragon, Kent-road.*
1826. Feb. 23.	Donkin, Lieut.-Gen. Sir Rufane Shaw, K.C.B. G.C.H. F.G.S. M.R.S.L. 33 *Park-street, Grosvenor-square; and Lower Caversham, Oxfordshire.*
1830. Jan. 28.	Douglas, George, Esq. *Chilston, Kent.*
1816. Jan. 25.	* Douglas, Major-General Sir Howard, Bart. C.B. K.S.C. D.C.L. F.S.A. *Lord High Commissioner of the United States of the Ionian Islands.*
1826. Mar. 9.	Douglas, William Robert Keith, Esq.
1815. Mar. 16.	D'Oyly, Rev. George, D.D. *Rectory, Lambeth.*
1839. Feb. 28.	† Drew, Richard, Esq. *Trinity-house.*
1836. Feb. 4.	† Drory, George William, Esq. *Ghent.*
1818. Feb. 26.	Drury, Rev. Henry, M.A. F.S.A. *Harrow.*
1814. June 9.	Ducie, Thomas Reynolds Earl. F.S.A. 2 *Seamor-place, Curzon-street.*
1808. Dec. 8.	Duckett, Sir George, Bart. M.A. F.S.A. F.G.S. M.R.S. *Roydon, near Ware, Hertfordshire.*
1833. Apr. 18.	Dundas, Robert Adam, Esq. 97 *Eaton-square.*
1825. Mar. 10.	D'Urban, Major-General Sir Benjamin, K.C.B. K.C.H. K.T.S. *Governor of the Cape of Good Hope.*
1824. Feb. 19.	Durham, Edward Maltby, D.D. Lord Bishop of. F.S.A. 28 *Curzon-street; and Aukland Castle, Durham.*
1799. Apr. 11.	East, Right Hon. Sir Edward Hyde, Bart. M.R.A.S. *Paladium-office, Waterloo-bridge; and Minchenden-house, Southgate.*
1838. Jan. 25.	† Eastlake, Charles Lock, Esq. R.A. 13 *Upper Fitzroy-street.*
1817. June 5.	Ebrington, Hugh Viscount, Lord Lieutenant of Ireland. 17 *Grosvenor-square.*
1822. Nov. 14.	Edgeworth, Lovell, Esq. *Edgeworth's-town, Ireland.*
1826. Jan. 12.	† Edmonstone, Neil Benjamin, Esq. 49 *Portland-place.*
1829. Feb. 26.	Edwards, W. F., M.D. *Rue Louis-le-Grand No.* 26, *Paris.*
1835. Feb. 5.	† Edye, John, Esq. 27 *Doughty-street, Mecklenburgh-square.*
1831. Feb. 10.	Egerton, Sir Philip de Malpas Grey, Bart. M.P. F.G.S. 111 *Jermyn-street; and Oulton-park, Cheshire.*
1815. Mar. 2.	Elliot, Sir William Francis, Bart. *Stobb's Castle; and Wells, N.B.*
1834. June 5.	Elliot, Hon. George, Captain in the Royal Navy. *Admiralty.*
1829. Mar. 19.	Elliotson, John, M.D. Coll. Reg. Med. Socius. 37 *Conduit-street.*

FRANKLIN INSTITUTE

Date of Election.	
1835. Nov. 26.	† Elliott, Charles, Esq. 47 *Portland-place.*
1832. Apr. 5.	Elliott, Rev. Charles Boileau, M.A. 47 *Portland-place; and Tattingstone, Suffolk.*
1811. May 30.	* Ellis, Sir Henry, K.H. B.C.L. Sec. S.A. Hon. M.R.I.A. Hist. Scand. Holm. et Soc. Reg. Antiq. Hafn. Socius.—Soc. Reg. Antiq. Franc. Corresp. Principal Librarian of the British Museum. *British Museum.*
1819. Feb. 11.	Ellis, Right Hon. Henry, F.G.S.
1801. Mar. 12.	Ellis, John, Esq. F.L.S.
1832. June 7.	† Elphinstone, Howard, Esq. M.A. F.G.S. 19 *Eaton-place, Belgrave-square.*
1827. Mar. 8.	Everest, Lieut.-Colonel George, Bengal Artillery, F.G.S. F.R.A.S. M.R.A.S. *Surveyor-General of India.*
1824. Jan. 8.	Faraday, Michael, Esq. D.C.L., Fullerian Professor of Chemistry in the Royal Institution of Great Britain. Hon. Mem. R.S.E., C.P.S. F.G.S. Acad. Imp. Sc. Petrop. Socius Honor.—Acad. Reg. Sc. Holm., Soc. Reg. Sc. Hafn., Acad. Reg. Sc. Mut. Acad. Amer. Art. et Sc. Bost. Socius, Instit. Reg. Sc. Paris., et Acad. Reg. Sc. Berolin., Soc. Georg. Florent., Soc. Philom. Paris, Acad. Reg. Med. Paris. Corresp. 21 *Albemarle-street.*
1830. Jan. 28.	† Farquharson, Rev. James, M.A. LL.D. *Alford, Aberdeenshire.*
1839. May 2.	† Farre, Arthur, M.B. *Charter-house-square.*
1835. April 2.	† Featherstonhaugh, G. W., Esq.
1816. Feb. 29.	Fellowes, Sir James, Knt. M.D. Coll. Reg. Med. Socius. *Adbury-house, near Newbury.*
1805. Mar. 7.	Ferguson, Robert, Esq. F.R.S.E. F.G.S. 18 *Portman-square; and Raith, Kirkaldy, Fifeshire.*
1836. Mar. 3.	Field, Joshua, Esq. *Cheltenham-place, Lambeth.*
1825. Jan. 27.	Fisher, Rev. George, M.A. F.R.A.S. *Royal Hospital, Greenwich.*
1815. Nov. 9.	Fitton, William Henry, M.D. F.L.S. F.G.S. F.R.A.S. Coll. Reg. Med. Socius. *Norwood, Surrey.*
1816. May 2.	Fitzgerald and Vesey, William Vesey Lord. Trust. Brit. Mus. M.R.I.A. *New-street, Spring-gardens.*
1811. Jan. 17.	Fitzwilliam, Charles William Earl, F.S.A. F.G.S. *Mortimer-house, Grosvenor-place; and Wentworth-house, near Rotherham, Yorkshire.*
1806. Feb. 27.	FitzWygram, Sir Robert, Bart. D.C.L. M.R.I.A. F.S.A. 10 *Connaught-place.*
1839. Mar. 21.	Fletcher, Thomas William, Esq. *Wurdley, Worcester.*
1834. Apr. 10.	† Folkes, Sir William Browne, Bart. 30 *Cavendish-square; and Hillington-hall, Lynn.*
1832. June 7.	Forbes, James David, Esq., Professor of Natural Philosophy in the University of Edinburgh. F.R.S.E. F.G.S. *Edinburgh.*
1829. Feb. 5.	Forbes, John, M.D. *Chichester.*
1822. Feb. 21.	Forbes, William Nairn, Esq. F.G.S.
1828. June 12.	† Forshall, Rev. Josiah, M.A. F.S.A. M.R.S.L. *British Museum.*
1821. Feb. 22.	Forster, Edward, Esq. V.P.L.S. 11 *Mansion-house-street; and Woodford, Essex.*
1802. April 1.	Fowler, Richard, M.D. F.S.A. *Salisbury.*
1821. July 12.	Franck, James, M.D. F.G.S. Coll. Reg. Med. Socius. 26 *Hertford-street.*
1823. Feb. 20.	Franklin, Sir John, Knt. Captain in the Royal Navy, D.C.L. F.L.S. F.G.S. F.R.A.S. Soc. Geogr. Paris. Corresp. *Governor of Van Diemen's Land.*
1821. Dec. 12.	Franks, William, Esq. M.A. *Wood-hill, Hatfield, Hertfordshire.*
1837. June 8.	Frere, George Edward, Esq. *Twerton, near Bath.*
1834. Apr. 10.	† Freshfield, James William, Esq. F.G.S. 9 *Upper Wimpole-street; and Leatherhead, Surrey.*

Date of Election.	
1820. Mar. 16.	Friend, Matthew Curling, Esq. Lieut. Royal Navy. *George Town, Van Diemen's Land.*
1839. Jan. 10.	† Frodsham, William James, Esq. *Change-alley, Cornhill.*
1834. Dec. 18.	† Galloway, Thomas, Esq. M.A. Sec. R.A.S. *Serjeant's-inn, Fleet-street.*
1816. April 4.	Gardiner, Rev. Samuel John, M.A.
1807. Mar. 5.	Garrow, Right Hon. Sir William, Knt. *Pegwell.*
	Garvagh, George Lord, F.S.A. 26 *Portman-square.*
1839. Mar. 21.	Gaskin, Rev. Thomas, M.A. *Jesus-college, Cambridge.*
1796. Feb. 18.	Gibbes, Sir George Smith, Knt. M.D. F.L.S. Coll. Reg. Med. Socius. *Bath.*
1791. Nov. 17.	Gilbert, Davies, Esq. D.C.L.—Hon. M.R.S.E. Hon. M.R.I.A. F.S.A. F.L.S. V.P.G.S. F.R.A.S.—President of the Royal Geological Society of Cornwall. 27 *Gower-street; East Bourne, Sussex; and Tredrea, Penzance, Cornwall.*
1834. Apr. 10.	Gilbert, John Davies, Esq. M.A. *East Bourne, Sussex; and Tredrea, Cornwall.*
1788. June 5.	Glasgow, George Earl of, G.C.H. F.S.A. *Camden-hill, Kensington.*
1828. Mar. 27.	Glenelg, Charles Lord, D.C.L. M.R.S.L. 11 *Great George-street, Westminster; and Glenelg, Inverness.*
1832. June 7.	† Glover, Rev. George, M.A., Archdeacon of Sudbury. *Southreppo, Norfolk.*
1838. Feb. 8.	Glynn, Joseph, Esq. *Butterley, Derbyshire.*
1839. Mar. 7.	† Godwin, George, jun., Esq., F.S.A. 11 *Pelham-crescent, Brompton.*
1808. May 26.	Goldingham, John, Esq. F.R.A.S. M.R.A.S. *Worcester.*
1828. Mar. 13.	Goldsmid, Isaac Lyon, Esq. F.S.A. F.L.S. F.G.S. F.R.A.S. M.R.S.L. *Park-lodge, Regent's-park.*
1819. Jan. 29.	Gompertz, Benjamin, Esq. F.R.A.S. *Kennington-terrace, Vauxhall.*
1824. April 1.	Goodenough, Edmund, D.D. Dean of Wells. *The Deanery, Wells.*
1835. April 2.	† Gordon, James Alexander, M.D. 2 *Finsbury-square.*
1801. June 11.	Gordon, Lieut.-General Sir James Willoughby, Bart. K.C.B. G.C.H. *Near the Royal Hospital, Chelsea.*
1830. Dec. 9.	Gordon, Henry Percy, Esq. M.A. *Near the Royal Hospital, Chelsea.*
1821. Feb. 8.	Gordon, Thomas, Esq. *Zante, Greece.*
1820. Apr. 27.	Goulburn, Right Hon. Henry, D.C.L. 1 *Upper Berkeley-street.*
1831. Dec. 22.	Graham, Right Hon. Sir James R. G., Bart. 46 *Grosvenor-place; and Netherby, Cumberland.*
1836. Dec. 15.	† Graham, Thomas, Esq., M.A. F.R.S. Ed. Professor of Chemistry in the University-college, London.—Acad. Reg. Sc. Berolin. Corresp. 9 *Torrington-square.*
1791. Mar. 10.	Grant, Lewis Alexander, Esq.
1836. Feb. 4.	Grant, Robert Edmond, M.D. F.R.S. Ed. Fullerian Professor of Physiology in the Royal Institution of Great Britain. 10 *Seymour-place, Euston-square.*
1817. Nov. 20.	Granville, Augustus Bozzi, M.D. F.G.S. M.R.A.S. Acadd. Reg. Sc. Brux., et Taur.: Acadd. Luc. et Pat.: Socc. Georg. Flor., Ital., Vienn., Sc. Nat. Neap., Athen. Ven., Philom. Paris., Socius.—Acad. Imp. Sc. Petr. Corresp. 16 *Grafton-street, Bond street; and Rosemont, Great Missenden, Buckinghamshire.*
1832. Feb. 2.	Gravatt, William, Esq. 7 *Delahay-street, Westminster.*
1839. Apr. 18.	Graves, John Thomas, M.A. 8 *Gray's-inn-square.*
1816. Feb. 15.	Gray, Francis Lord. *Kinfauns Castle, Perth.*
1832. Feb. 2.	Gray, John Edward, Esq. F.G.S. F.R.G.S. Imp. Hist. Nat. Mosc. Acadd. Lync. Romæ. Sci. Nat. Philad. et Hist. Nat. Boston., Socius. *British Museum; and Eliot Vale, Blackheath.*

Date of Election.	
1825. Feb. 24.	Green, Joseph Henry, Esq., Professor of Anatomy to the Royal Academy, F.G.S. *Barnet.*
1807. Mar. 5.	Greenough, George Bellas, Esq. President of the Royal Geographical Society. F.L.S. F.G.S. M.R.A.S. *Grove-house, Regent's-park.*
1833. Feb. 7.	Greig, Woronzow, Esq. M.A. 2 *Mitre-court-buildings, Temple.*
1830. June 10.	Gresswell, Rev. Richard, M.A. *Worcester-college, Oxford.*
1815. Feb. 16.	Grey, Sir Thomas, Knt. M.D. F.L.S. *Ramsgate.*
1834. Apr. 10.	† Griffith, Edward, Esq. F.S.A. F.L.S. *Downshire-hill, Hampstead.*
1806. May 1.	Griffiths, John, Esq.
1830. Apr. 22.	Grover, Captain John.
1839. June 20.	Guest, Edwin, Esq. 4 *King's-bench-walk, Temple.*
1830. June 10.	Guest, Sir Josiah John, Bart. F.G.S. 14 *Grosvenor-square; and Dowlais Iron-works, Glamorganshire.*
1806. Jan. 16.	Guillemard, John Lewis, Esq. M.A. F.L.S. F.G.S. M.R.A.S. Soc. Amer. Philad. Socius. 27 *Gower-street; and Woodford, Essex.*
1839. Mar. 7.	† Gulliver, George, Esq. *Regent's-park Barracks.*
1818. Jan. 15.	Gurney, Hudson, Esq. V.P.S.A. M.R.S.L. 9 *St. James's-square; and Keswick-hall, near Norwich.*
1827. May 24.	Guthrie, George James, Esq. 4 *Berkeley-street, Piccadilly.*
1801. May 7.	Hailstone, Rev. John, M.A. F.L.S. F.G.S. *Trumpington, Cambridgeshire.*
1810. Mar. 8.	Halford, Sir Henry, Bart. G.C.H. Physician to the Queen, Trust. Brit. Mus.—President of the Royal College of Physicians. F.S.A. 16 *Curzon-street; and Wistow-hall, near Market-Harborough.*
1816. Mar. 28.	Hall, Basil, Captain in the Royal Navy, D.C.L. F.R.S.E. F.G.S. F.R.A.S. M.R.A.S. *Edinburgh.*
1820. Apr. 27.	* Hall, Sir John, Bart. F.R.S.E. F.G.S. *Douglass, Dunbar, Haddingtonshire.*
1832. Apr. 5.	Hall, Marshall, M.D. F.R.S.E. 14 *Manchester-square.*
1827. Nov. 22.	Hall, Thomas Henry, Esq. M.A. 49 *Tavistock-square.*
1821. Mar. 8.	Hallam, Henry, Esq. M.A. Trust. Brit. Mus. V.P.S.A. F.G.S. F.R.A.S. M.R.S.L. Instit. Reg. Sc. Paris Socius. 67 *Wimpole-street.*
1839. May 30.	† Halliwell, James Orchard, Esq. F.S.A. L. & E. F.R.A.S. M.R.S.L. Soc. Reg. Antiq. Franc., Soc. Reg. Antiq. Septen. Hafn., Soc. Ethnol. Paris., Soc. Reg. Geogr. Paris., Soc. Asiatic. Paris., Corresp. *Jesus-college, Cambridge; and* 35 *Alfred-place, Bedford-square.*
1834. Apr. 10.	† Halswell, Edmund S., Esq. M.A. *Gore-lodge, Brompton.*
1835. Feb. 5.	† Hamett, Sir John, Knt. M.D. *Hortulan-place, King's-road, Chelsea.*
1808. Jan. 14.	Hamilton and Brandon, Alexander Duke of, F.S.A. 12 *Portman-square; and Hamilton-palace, Lanarkshire.*
1828. Jan. 17.	Hamilton, Rev. Henry Parr, M.A. F.R.S.E. F.G.S. F.R.A.S. *Trinity-college, Cambridge.*
1813. Apr. 8.	Hamilton, William Richard, Esq. F.S.A. M.R.S.L. Acad. Reg. Sc. Berolin. Socius Honor. *Stanley-grove, King's-road, Chelsea.*
1838. Jan. 18.	† Hansler, Sir John J., Knt. F.S.A. 48 *Tavistock-square.*
1824. Apr. 29.	Harcourt, Rev. William Venables Vernon, M.A. F.G.S. *Weldrake, near York.*
1838. Apr. 5.	† Hardwick, John, Esq. D.C.L. 5 *K, Albany, Piccadilly.*
1838. Dec. 8.	Hardwick, Philip, Esq. F.S.A. 60 *Russell-square.*

Date of Election.	
1839. Jan. 17.	† Hardy, Peter, Esq. 37 *Old Jewry.*
1812. Dec. 10.	Hare, Francis George, Esq.
1823. May 29.	Harford, John Scandret, Esq. D.C.L.
1835. Feb. 5.	† Harris, John Greathed, Esq. M.A. *Old Palace-yard.*
1831. June 2.	Harris, William Snow, Esq. *Plymouth.*
1807. Feb. 5.	Harrison, Sir George, Knt. K.C.H. F.S.A. 4 *Spring-gardens-terrace.*
1825. Feb. 17.	Harvey, Henry, Esq. F.R.A.S. *Hill-house, Streatham, Surrey.*
1835. April 2.	† Harvey, Colonel Sir Robert John, C.B. K.T.S. K.S.B. F.S.A. *Mousehold-house, near Norwich.*
1827. May 24.	† Harwood, John, M.D. F.L.S. *St. Leonard's, Hastings.*
1812. Jan. 9.	Hasted, Rev. Henry, M.A. F.L.S. *Bury, Suffolk.*
1797. Mar. 9.	Hatchett, Charles, Esq. F.R.S.E. F.S.A. F.L.S. Instit. Reg. Sc. Paris. Corresp.—Acad. Reg. Sc. Monach., et Soc. Œcon. Petrop., Socius. *Belle-Vue-house, Chelsea; and Bullington, Lincolnshire.*
1821. Nov. 15.	Haughton, Sir Graves Chamney, K.H. M.A. Hon. M.R.I.A. M.R.A.S., Instit. Reg. Sc. Paris. Socius. Acad. Reg. Berolin. Corresp. 14, *Grafton-street, Bond-street.*
1834. Dec. 18.	Hawkins, Bisset, M.D. 30 *Golden-square.*
1821. May 24.	* Hawkins, Edward, Esq. F.S.A. F.L.S. *British Museum.*
1791. May 5.	Hawkins, John, Esq. *Quay-house, Devonshire.*
1826. Jan. 12.	Hawkins, John, Esq. *Bignor-park, Petworth, Sussex.*
1830. June 10.	Hawkins, John Heywood, Esq. M.A. F.G.S. 8 *Suffolk-street; and Bignor-park, Petworth, Sussex.*
1835. Nov. 19.	† Hawkins, Rev. William B. L., M.A. 23 *Great Marlborough-street.*
1778. June 18.	Hay, Alexander, M.D.
1814. Mar. 3.	Hay, Robert William, Esq. F.S.A. 21 *Queen-street, May-fair.*
1818. May 28.	* Heath, George Crauford, Esq. *Cambridge.*
1791. Feb. 24.	Heberden, William, M.D. Coll. Reg. Med. Socius. 39 *Jermyn-street.*
1829. Mar. 12.	† Hennell, Henry, Esq. *Apothecaries'-hall, Bridge-street, Blackfriars.*
1834. Apr. 10.	Henry, William Charles, M.D. *Haffield, near Ledbury, Herefordshire.*
1813. May 27.	Herschel, Sir John Frederick William, Bart. D.C.L. M.A.—VICE PRESIDENT.—F.R.S.E. M.R.I.A. F.G.S. President of the Royal Astronomical Society. M.C.P.S. Instit. Reg. Sc. Paris. Corresp.—Acadd. Imp. Sc. Petrop., et Reg. Sc. Brux.: Hafn., Harl. et Neap.: Acadd. Lync. Romæ, Pat., Bonon., Panorm., Gioen. Catan. et Divion. ex intim.: Socc. Philom. Paris., Ital. Mut., Helvet., Socius.—Acad. Reg. Sc. Berol., Soc. Reg. Sc. Gotting. Corresp. *Slough, near Windsor, Berks.*
1839. Feb. 7.	Heywood, James, Esq. F.S.A. 52 *Queen-street, Grosvenor-square.*
1820. Mar. 23.	Higman, Rev. John Philip, M.A. F.G.S. F.R.A.S. *Trinity-college, Cambridge.*
1839. Jan. 10.	† Hilton, John, Esq. *St. Thomas's-street, Southwark.*
1809. Dec. 21.	Hoare, Charles, Esq. F.S.A. 37 *Fleet-street.*
1784. June 17.	Hoare, Sir Henry Hugh, Bart., F.S.A. 7 *York-street, St. James's.*
1814. May 19.	Hobhouse, Right Hon. Sir John Cam, Bart. M.A. 42 *Berkeley-square.*
1811. June 27.	Hoblyn, Thomas, Esq. F.L.S.
1831. Apr. 14.	Hodgson, Joseph, Esq. *Birmingham.*
1810. July 5.	* Hodgson, Robert, D.D. Dean of Carlisle, F.G.S. 15 *Grosvenor-street; and Hillingdon, Uxbridge.*

Date of Election.	
1839. June 20.	† Hogg, John, Esq. M.A. F.L.S. 12 *King's-bench-walk, Temple.*
1837. Jan. 19.	Holland, Charles, M.D. 16 *Queen-street, May-fair.*
1811. Dec. 19.	Holland, Henry Richard Vassal Lord, F.S.A. 33 *South-street, Grosvenor-square; and Holland-house, Kensington.*
1815. Jan. 19.	Holland, Henry, M.D. F.G.S. Coll. Reg. Med. Socius. 25 *Brook-street.*
1826. Feb. 2.	Holman, James, Esq. Lieutenant in the Royal Navy, F.L.S. 37 *Gerrard-street, Soho; and Windsor.*
1825. Apr. 21.	Home, Sir Everard, Bart. Captain in the Royal Navy, F.S.A.
1812. Jan. 9.	Hooker, Sir William Jackson, K.H. LL.D., Regius Professor of Botany, Glasgow, F.S.A. F.L.S. F.G.S. Acad. Cæs. Nat. Cur. Socius. *Glasgow.*
1834. June 5.	† Hope, Rev. Frederick William, M.A. F.L.S. 56 *Upper Seymour-street.*
1832. June 7.	† Hope, James, M.D. 13 *Lower Seymour-street.*
1810. May 31.	Hope, Thomas Charles, M.D., Professor of Chemistry, Edinburgh. V.P.R.S.E. *Edinburgh.*
1837. June 1.	† Hopkins, William, Esq. M.A. *St. Peter's-college, Cambridge.*
1834. Feb. 6.	Horne, James, Esq. *Clapham-common.*
1813. Nov. 11.	Horner, Leonard, Esq. F.R.S.E. V.P.G.S. Soc. Batav. Sc. Harlem. Socius. 2 *Bedford-place.*
1828. Jan. 10.	† Horsfield, Thomas, M.D. F.L.S. F.G.S. M.R.A.S. Acad. Cæs. Nat. Cur. Socius. 46, *Myddleton Square, Pentonville.*
1821. May 4.	Horton, Right Hon. Sir Robert John Wilmot, Bart. G.C.H. M.A.
1794. April 3.	Howard, Colonel Hon. Fulk Greville, F.S.A. 16 *Grosvenor-square.*
1821. Mar. 8.	Howard, Luke, Esq. *Bruce-grove, Tottenham; and Ackworth-villa, Pomfret.*
1834. Apr. 10.	Hudson, Robert, Esq. F.G.S. *Clapham-common.*
1818. Jan. 8.	Hume, Joseph, Esq. M.P. 6 *Bryanston-square.*
1819. Nov. 11.	Hunt, Rev. George, M.A. F.S.A. *Egg Buckland, near Plymouth.*
1837. April 6.	† Hunter, Robert, Esq. F.S.A. 46 *Burton-cresent.*
1819. Nov. 18.	Hustler, Rev. James Devereux, B.D. *Euston-rectory, near Thetford, Norfolk.*
1829. Mar. 19.	Hutchinson, Major George Henry. *Bengal.*
1828. Mar. 13.	† Hutchison, Alexander Copland, Esq. Soc. Medico. Chir. Berolin. Corresp. F.R.S.E. 83 *Wimpole-street.*
1838. May 31.	Hymers, Rev. John. *St. John's-college, Cambridge.*
1813. Mar. 4.	Inglis, Sir Robert Harry, Bart. LL.D. M.P. Trust. Brit. Mus. F.S.A. F.R.A.S. 7 *Bedford-square; and Battersea-rise, Clapham.*
1815. April 6.	* Ivory, James, Esq., K.H. M.A. Instit. Reg. Sc. Paris., et Soc. Reg. Sc. Gotting., Corresp. 8 *Claremont-row, Pentonville.*
1807. Apr. 23.	Jacob, William, Esq. Instit. Sc. Paris Corresp. 41 *Cadogan-place, Sloane-street.*
1826. May 25.	Jameson, Robert, Esq., Regius Professor of Natural History, Edinburgh. F.R.S.E. Hon. M.R.I.A. F.L.S. F.G.S. Acad. Reg. Sc. Neap.: Socc. Reg. Sc. Dan., Imp. Hist. Nat. Mosc., Hist. Nat. Veter., et Paris., Philom. Paris., Amer. Philad., Phil. et Hist. Nov.-Ebor., Socius.—Acad. Reg. Sc. Berol., Corresp. *Edinburgh.*
1834. June 5.	Jekyll, Joseph, Esq. M.A. *Christ-church, Oxford.*
1821. Mar. 1.	Jennings, Rev. Philip, D.D. *Hampstead-green.*
1838. Mar. 15.	† Jervis, Thomas Best, Esq. Major, East India Company's Engineers. F.G.S. F.R.A.S. Provisional Surveyor-General of India.
1817. June 26.	Johnson, James Rawlins, M.D. F.L.S.

Date of Election.

1836. Mar. 10. † Johnson, Edward John, Esq. Captain, Royal Navy. 14 *Cambridge-terrace, Edgeware-road.*

1810. Nov. 22. Johnson, Right Hon. Sir Alexander, Knt. F.S.A. V.P.R.A.S. 19 *Great Cumberland-place; and York-house, Twickenham.*

1838. Jan. 18. Johnson, Rev. George Henry Sacheverell, M.A. *Queen's-college, Oxford.*

1837. June 15. † Johnston, James F. W., Esq., M.A. F.R.S.Ed. Professor of Chemistry and Mineralogy in the University of Durham.

1835. June 4. † Jones, Thomas, Esq. F.R.A.S. 62 *Charing-cross; and* 10 *Albany-road, Camberwell.*

1838. Dec. 6. † Kelland, Rev. Philip, M.A. *Queen's-college, Cambridge.*

1822. Mar. 28. Kidd, John, M.D., Regius Professor of Medicine, and Aldrich's Professor of Anatomy, Oxford, F.G.S. Coll. Reg. Med. Socius. *Oxford.*

1834. Dec. 18. Kiernan, Francis, Esq. 33 *Beaumont-street, Devonshire-place.*

1824. Feb. 26. King, Philip Parker, Esq. Captain in the Royal Navy, F.L.S. *Dunheved, New South Wales.*

1818. Mar. 5. Kirby, Rev. William, M.A. F.L.S. F.G.S. Acad. Cæs. Nat. Cur., et Soc. Nat. Scrutat. Berol., Socius. *Barham, near Ipswich.*

1830. Mar. 4. Knowles, Sir Francis Charles, Bart. M.A. F.R.A.S. *Harcourt-buildings, Temple.*

1821. July 5. Knowles, John, Esq. 34 *Bridge-street, Blackfriars.*

1810. Jan. 18. * Konig, Charles, Esq. K.H. Hon. M.R.I.A. F.L.S. Acad. Reg. Sc. Monach. Socius.—Acad. Imp. Sc. Petrop., et Soc. Reg. Gotting., Corresp.—Soc. Imp. Hist. Nat. Mosc. Socius.—Acad. Panorm., et Soc. Veterav., Sodalis. *British Museum.*

1791. Mar. 31. Lambert, Aylmer Bourke, Esq. Hon. M.R.I.A. F.S.A. V.P.L.S. F.G.S. Acadd. Cæs. Nat. Cur., et Reg. Sc. Madrit., Socius. 26 *Grosvenor-street; and Boyton-house, Wiltshire.*

1811. Apr. 4. Lansdowne, Henry Marquis of, D.C.L. Trust. Brit. Mus. M.R.S.L. 52 *Berkeley-square; and Bowood-park, Wiltshire.*

1828. Feb. 28. † Lardner, Rev. Dionysius, LL.D. F.R.S.E. F.R.I.A. Hon. M.C.P.S. F.R.A.S. 9 *Great Queen-street, Westminster.*

1801. Apr. 30. Latham, John, M.D. F.L.S. Coll. Reg. Med. Socius. *Broadwall-hall, Cheshire.*

1813. Nov. 11. Lawrence, William, Esq. 18 *Whitehall-place.*

1815. Apr. 13. Leake, Lieut.-Colonel William Martin, M.R.S.L. Acad. Reg. Sc. Berol. Socius. Honor. —Instit. Reg. Paris., Corresp. 50 *Queen Anne-street.*

1831. Feb. 24. Lee, John, LL.D. Treas. R.A.S. 5 *College, Doctor's-commons; and Hartwell-house, near Aylesbury, Buckinghamshire.*

1830. Mar. 25. Lee, Robert, M.D. 14 *Golden-square.*

1820. Nov. 16. Lefevre, John George Shaw, Esq. M.A. 1 *Somerset-place, Somerset-house.*

1817. June 12. Legh, Thomas, Esq. D.C.L. *Lyme-park, Cheshire.*

1822. May 23. Lemon, Sir Charles, Bart. 46 *Charles-street, Berkeley-square; and Carclew, near Falmouth, Cornwall.*

1836. May 5. † Lewis, Thomas Locke, Esq. Captain in the Royal Engineers, F.G.S. *Ibsley-cottage, Exeter.*

1835. April 2. † Leybourn, Thomas, Esq. F.R.A.S. *Royal Military College, Sandhurst.*

1822. June 27. Litchfield and Coventry, Samuel Butler, D.D. Lord Bishop of. *Palace, Litchfield.*

1833. June 6. Lihou, John, Esq. Captain in the Royal Navy. *Guernsey.*

1811. Mar. 7. Lincoln, John Kaye, Lord Bishop of. *Cambridge; and Buckden-palace, Huntingdonshire.*

1828. Jan. 17. † Lindley, John, Phil.D. F.L.S. Acad. Reg. Berol. Corresp.; Acad. Cæs. Nat. Cur.,

Date of Election.	
	Socc. Physiogr. Lund. Linn. Holm., Socius.—Soc. Batav. Sc., Lyc. Nat. Hist. Nov.-Ebor., Socius Honor.—Prof. Bot. Univ. Coll. Lond. 21 *Regent-street.*
1832. Feb. 2.	Lister, Joseph Jackson, Esq. *Upton, Essex.*
1836. Feb. 4.	Llewelyn, John Dillwyn, Esq. *Penllergare, Glamorgan.*
1818. Mar. 12.	Lloyd, Edward, Esq. Captain in the Royal Navy.
1834. Apr. 10.	Lloyd, Rev. William Forster, M.A., Professor of Political Economy in the University of Oxford. *Oxford.*
1836. Jan. 21.	Lloyd, Rev. Humphrey, M.A. M.R.I.A. *Dublin.*
1838. Feb. 22.	† Locke, Joseph, Esq. 6 *Chester-terrace, Regent's-park.*
1811. Dec. 5.	Locker, Edward Hawke, Esq. F.S.A. *Royal Hospital, Greenwich.*
1834. Dec. 18.	† Lowe, George, Esq. 39 *Finsbury Circus.*
1810. July 5.	Lowther, William Viscount, F.S.A. *Carlton-terrace.*
1821. Nov. 15.	Lubbock, Sir John William, Bart. F.L.S. F.G.S. 23 *St. James's-place.*
1829. Jan. 15.	Lubbock, John William, Esq. M.A.—Vice-President and Treasurer.—Vice-Chancellor of the University of London. F.L.S. F.R.A.S. 29 *Eaton-place, Belgrave-square.*
1819. Feb. 11.	Lunn, Rev. Francis, B.A. *Butleigh, Glastonbury.*
1826. Feb. 2.	Lyell, Charles, jun. Esq. M.A. F.L.S. F.G.S. 16 *Hart-street, Bloomsbury.*
1826. Apr. 13.	Lyndhurst, John Singleton Lord, D.C.L. 25 *George-street, Hanover-square.*
1811. Feb. 21.	Macartney, James, M.D. F.L.S. Trinity-college, Dublin.
1818. Nov. 5.	Macclesfield, George Earl of, F.R.A.S. 9 *Conduit-street.*
1838. Mar. 29.	† MacGillivray, Simon, Esq. F.S.A. *Blackheath.*
1816. Mar. 14.	MacGrigor, Sir James, Bart. F.R.S.E. Col. Reg. Med. Socius. *Camden-hill, Kensington.*
1824. Apr. 29.	Macintosh, Charles, Esq. *Glasgow.*
1815. Apr. 13.	Mackenzie, Sir George Steuart, Bart. F.R.S.E. *Coul, Ross-shire.*
1817. May 15.	Mackie, Rev. John William, M.A. *Siddons-house, Upper Baker-street.*
1827. June 14.	Mackinnon, William Alexander, Esq. M.A. F.S.A. F.G.S. 4 *Hyde-park-place; and Newton-park, Lymington, Hants.*
1839. May 30.	† Mackmurdo, Gilbert Wakefield, Esq. *St. Thomas's Hospital.*
1831. Dec. 8.	Maclear, Thomas, Esq. F.R.A.S. Astronomer Royal at the Cape of Good Hope.
1809. Jan. 19.	MacLeay, Alexander, Esq. F.L.S. Acad. Reg. Sc. Holm., Socius, et Acad. Reg. Sc. Taurin. Corresp. *Sydney, New South Wales.*
1838. April 5.	† Macneill, John, Esq. F.R.A.S. M.R.I.A. 9 *Whitehall-place.*
1832. Feb. 2.	† Madden, Sir Frederick, K.H. F.S.A. Soc. Reg. Antiq. Hafn., Socius. *British Museum.*
1817. June 12.	Maddy, Rev. John, D.D. F.S.A. F.R.A.S. *Somertown, Bury St. Edmund's.*
1819. June 24.	Magrath, Sir George, K.H. M.D. M.R.I.A. F.L.S F.G.S. *Plymouth.*
1827. Mar. 22.	† Mahon, Philip Henry Viscount, D.C.L. 41 *Grosvenor-place; and Chevening-place, Kent.*
1839. Apr. 18.	† Maitland, Rev. Samuel Roffy. *Lambeth-palace.*
1829. May 28.	Maitland, Ebenezer Fuller, Esq. F.S.A. 3 *Bryanston-square; and Henley-on-Thames, Oxfordshire.*
1821, June 28.	* Majendie, Ashhurst, Esq. F.G.S. *Hedingham-castle, Essex.*
1831. May 12.	Manby, Captain George William. *Yarmouth.*
1825. Jan. 20.	Mangles, James, Esq. Captain in the Royal Navy.
1802. May 20.	Mansfield, William Earl of, F.S.A. *Langham-house; and Kenwood, Middlesex.*
1825. Nov. 24.	Mantell, Gideon Algernon, Esq. LL.D. F.L.S. F.G.S. Coll. Reg. Med. Socius. Soc.

Date of Election.	
	Philom. Paris. Corresp., et Acadd., Philad. et Connect. Socius Honor. *Crescent-lodge, Clapham-common.*
1836. Jan. 28.	Marcet, Francis, Esq. *Geneva.*
1816. Mar. 28.	Markland, James Heywood, Esq. F.S.A. 14 *Whitehall-place.*
1819. May 13.	Marryatt, Frederick, Esq. Captain in the Royal Navy, F.L.S. *Wimbledon.*
1832. Feb. 2.	Mauley, Lord de. 11 *Hanover-square.*
1829. Feb. 26.	Maxwell, John, Esq. *Pollock, Renfrewshire.*
1818. Jan. 29.	Mayne, John Thomas, Esq. F.S.A. Soc. Phil. Neap. Socius. *Harcourt-buildings, Temple; and Teffont-house, Salisbury.*
1827. Mar. 1.	† Mayo, Rev. Charles, B.D. F.S.A. *Colesgrove, near Cheshunt, Hertfordshire.*
1828. Apr. 17.	† Mayo, Herbert, Esq. 19 *George-street, Hanover-square.*
1835. June 4.	† Mayo, Thomas, M.D. Col. Reg. Med. Socius. 56 *Wimpole-street.*
1827. Feb. 1.	Melville, Alexander, Esq. 16 *Upper Harley-street.*
1817. May 15.	Melville, Robert Viscount, K.T. F.R.A.S. 3 *Somerset-pl.; and Melville-castle, Edinburgh.*
1838. May 3.	† Merewether, Rev. John, D.D. Dean of Hereford, F.S.A.
1827. May 24.	Miller, Lieut.-Colonel George, C.B. 2 *Stone-buildings, Lincoln's-inn.*
1838. Feb. 8.	Miller, William Hallows, Esq. M.A. *St. John's-college, Cambridge.*
1836. Mar. 3.	Minto, Gilbert Elliot Murray Kynynmound Earl of. *Admiralty; and Minto-castle, Roxburghshire.*
1835. Nov. 26.	† Molesworth, Sir William, Bart. M.P. 79 *Eaton-square; and Pencarrow, Cornwall.*
1836. June 16.	Montefiore, Sir Moses, Knt. *Grosvenor-gate, Park-lane; and East Cliff-lodge, Ramsgate.*
1806. May 6.	Moor, Major Edward, F.S.A. M.R.A.S. *Bealings, near Woodbridge, Suffolk.*
1835. Apr. 2.	† Moore, George, Esq. F.S.A. 64 *Lincoln's-inn-fields.*
1827. Feb. 8.	Moreau, César, Esq. Acadd. Reg. Divion., Burd., et Masil., Socius. *Paris.*
1835. Apr. 2.	† Morgan, Arthur, Esq. 26 *New Bridge-street, Blackfriars.*
1816. May 30.	Morgan, Charles, Esq. F.S.A. F.L.S. *Pall-mall; and Tredegar-house, near Newport, Monmouthshire.*
1832. Feb. 2.	† Morgan, Octavius, Esq. M.A. F.S.A. 70 *Pall-mall; and Tredegar-park, Monmouthshire.*
1819. Feb. 4.	Morier, James Esq. 22 *Charles-street, Berkeley-square.*
1795. Feb. 26.	* Morley, John Earl of. *Kent-house, Knightsbridge.*
1831. Mar. 10.	Morris, John Carnac, Esq.
1839. Feb. 7.	† Moseley, Rev. Henry, M.A. Professor of Natural Philosophy and Astronomy, King's-college, London.
1830. Feb. 18.	Moss, Joseph William, M.B. *Dudley.*
1822. Dec. 5.	Mudge, Richard Zachariah, Esq. Lieut.-Colonel in the Royal Engineers. *Beechwood, Plympton, Devon.*
1820. Jan. 13.	Munster, George Earl of, M.R.A.S. M.R.S.L. Instit. Sc. Paris. Corresp. 13 *Belgrave-street; and Upper-lodge, Bushy-park, Middlesex.*
1826. Apr. 6.	Murchison, Roderick Impey, Esq. F.G.S. 16 *Belgrave-square.*
1805. July 4.	Murdoch, Thomas, Esq. F.S.A. 8 *Portland-place.*
1823. June 19.	Murray, Right Hon. Sir George, G.C.B. G.C.H. K.T.S. 5 *Belgrave-square; and Bleaden, Perthshire.*
1826. Mar. 16.	Mylne, William Chadwell, Esq. F.R.A.S. *New River-head.*
1820. May 18.	* Napier, Henry, Esq. Captain in the Royal Navy. *Florence.*
1817. June 12.	Napier, Macvey, Esq. F.R.S.E. *Edinburgh.*
1814. May 5.	Neave, Sir Thomas, Bart. F.S.A. 6 *Albemarle-street; and Dagnam-park, Rumford, Essex.*

Date of Election.	
1833. Feb. 7.	† Nolan, Rev. Frederick, LL.D. M.R.S.L. *Prittlewell, Essex.*
1816. Feb. 15.	Norfolk, Bernard Edward Duke of, E.M. F.S.A. 21 *St. James's-square.*
1830. May 27.	Northampton, Spencer Joshua Alwyne Marquess of.—PRESIDENT.—Trust. Brit. Mus., F.S.A. Hon. M.R.I.A. F.G.S. 145 *Piccadilly; and Castle Ashby, Northampton.*
1823. May 1.	Northumberland, Hugh Duke of, K.G. M.A. Trust. Brit. Mus. F.S.A. F.L.S. F.G.S. *Northumberland-house.*
1826. Feb. 2.	† Ogle, James Adey, M.D. F.R.A.S. Coll. Reg. Med. Socius. Lord Lichfield's, and Aldrich's, Professor of Medicine, Oxford. *Oxford.*
1786. Nov. 16.	Oldershaw, John, B.D. Archdeacon of Norfolk. *Harleston, Norfolk.*
1835. June 4.	Oliveira, Benjamin, Esq. F.S.A. 18 *Hyde-park-street.*
1819. Feb. 18.	Onley, Charles Savill, Esq. F.S.A. F.L.S. 22 *Great George-street, Westminster; and Stiested-hall, Essex.*
1824. Mar. 4.	Orford, Horatio Earl of. *Wolterton-park, Norfolk.*
1819. Feb. 25.	Ormerod, George, Esq. D.C.L. F.S.A. F.G.S. *Sedbury-park, Gloucestershire.*
1839. Apr. 11.	† Ormsby, H. Alexander, Esq. Lieutenant, Indian Navy. *India.*
1817. Dec. 18.	Ouseley, Right Hon. Sir Gore, Bart. G.C.H. F.S.A. M.R.A.S. M.R.S.L. Acad. Imp. Sc. Petrop. Socius. 41 *Upper Brook-street; and Woolmers, Hertfordshire.*
1838. May 3.	Outram, Benjamin Fonseca, M.D. F.R.G.S. 1 *Hanover-square.*
1834. Dec. 18.	Owen, Richard, Esq. F.G.S. F.L.S. Instit. Sc. Paris. Corresp. *Royal College of Surgeons, Lincoln's-inn-fields; and 6 Park Cottages, Regent's-park.*
1831. Dec. 8.	Oxmantown, William Lord, F.R.A.S. *Birr-castle, King's County, Ireland.*
1821. Nov. 15.	Palgrave, Sir Francis, K.H. Deputy Keeper of Her Majesty's Records. *Hampstead-green.*
1831. Dec. 8.	Palmer, Henry Robinson, Esq. 2 *Great George-street, Westminster.*
1821. June 21.	* Paris, John Ayrton, M.D. F.L.S. Coll. Reg. Med. Socius. 28 *Dover-street.*
1824. Mar. 4.	Parish, Sir Woodbine, K.C.H. F.S.A. F.G.S. 5 *Gloucester-place, Portman-square.*
1815. June 1.	Parker, Thomas Lister, Esq. F.S.A. F.L.S. 34 *Mount-street.*
1812. Feb. 20.	Parry, Charles Henry, M.D. *Bath.*
1821. Feb. 15.	Parry, Sir William Edward, Knt. D.C.L. Captain in the Royal Navy. F.R.A.S. Acad. Imp. Sc. Petrop. Socius. 2 *New-street, Spring-gardens.*
1837. Feb. 23.	† Partridge, Richard, Esq. 17 *New-street, Spring-gardens.*
1816. Mar. 7.	Pasley, Colonel Charles William, C.B. Royal Engineers. F.R.A.S. F.G.S. *Chatham.*
1818. Jan. 29.	Peacock, Very Rev. George, D.D. Dean of Ely. F.G.S. F.R.A.S. *Trinity-college, Cambridge.*
1833. Dec. 5.	Pearson, Sir Edwin, K.H. M.A. 31 *Conduit-street.*
1819. July 1.	Pearson, Rev. William, LL.D. F.R.A.S. 6 *Compton-terrace, Islington; and South Kilworth, near Welford, Northamptonshire.*
1826. Mar. 9.	Pearson, William, Esq. *Clapham.*
1832. Feb. 2.	Pechell, Sir Samuel John Brooke, Bart. Captain in the Royal Navy. 3 *Tilney-street.*
1822. Dec. 5.	Peel, Right Hon. Sir Robert, Bart. D.C.L. Trust. Brit. Mus. F.S.A. *Whitehall-gardens; and Drayton-Manor, Fazeley, Staffordshire.*
1835. Apr. 2.	† Pelly, John Henry, Esq. *Trinity House.*
1813. Feb. 11.	Pemberton, George, Esq. 15 *Park-street; and Bainbridge Holme, Durham.*
1827. May 24.	Pendarves, Edward William Wynne, Esq. M.A. F.G.S. 36 *Eaton-place, Belgrave-square; and Pendarves, Truro, Cornwall.*
1824. Nov. 18.	Penn, Richard, Esq. 6 *Whitehall.*
1792. Nov. 15.	Pennant, David, Esq. F.L.S. *Downing, near Holywell, Flintshire.*

Date of Election.	
1808. Jan. 28.	Pepys, William Hasledine, Esq. F.L.S. *Poultry.*
1838. May 3.	† Pereira, Jonathan, Esq. F.L.S. 20 *Artillery-place, Finsbury-square.*
1807. Dec. 10.	Petit, Louis Hayes, Esq. M.A. F.S.A. F.L.S. F.G.S. F.R.A.S. M.R.S.L. 9 *New-square, Lincoln's-inn.*
1817. Mar. 6.	Petre, William Francis Henry Lord. 3 *Mansfield-street; and Thorndon-hall, near Brentwood, Essex.*
1827. Feb. 1.	† Pettigrew, Thomas Joseph, Esq. F.S.A. F.L.S. M.R.A.S. Univ. Gotting. Phil. Doct.—Acad. Reg. Divion. Socius. 8 *Saville-street.*
1815. June 15.	* Phelps, John Delafield, Esq. F.S.A. *Chavenage-house, Tetbury, Gloucestershire.*
1826. Apr. 11.	Philip, Alexander Philip Wilson, M.D. F.R.S.E. 18 *Cavendish-square.*
1819. Jan. 29.	Phillipps, Sir Thomas, Bart. M.A. F.S.A. F.G.S. Hon. M.R.S.L. *Middle-hill, Worcestershire.*
1834. Dec. 18.	Phillips, Benjamin, Esq. 17 *Wimpole-street, Cavendish-square.*
1829. Mar. 5.	Phillips, Charles, Esq. Captain in the Royal Navy.
1834. Apr. 10.	† Phillips, John, Esq. F.G.S. *York.*
1822. Mar. 14.	* Phillips, Richard, Esq. F.R.S.E. 6 *Craig's-court, Charing-cross; and Camberwell-green.*
1820. Apr. 20.	Phillips, Thomas, Esq. R.A. F.S.A. 8 *George-street, Hanover-square.*
1791. Mar. 10.	Pocock, Sir George, Bart. *Bransgore-house, Ringwood, Hampshire.*
1829. April 9.	Pole, William, Esq. M.A. 3 *Stone-buildings, Lincoln's-inn.*
1829. April 9.	Pollock, David, Esq. F.R.A.S. M.R.A.S. M.R.S.L. *Dartmouth-house, Westminster.*
1816. Feb. 29.	Pollock, Sir Frederick, K.H. M.A. F.S.A. F.G.S. *Queen-square-house, Guildford-street.*
1838. Jan. 18.	† Porter, George Richardson, Esq. F.R.G.S. M.R.A.S. *Board of Trade, Whitehall.*
1837. June 8.	Portlock, Joseph Ellison, Esq. Captain of Royal Engineers, F.G.S. *Cork.*
1824. May 13.	Powell, Rev. Baden, M.A. F.R.A.S. Savilian Professor of Geometry, Oxford. *Oxford.*
1827. Feb. 8.	Prichard, James Cowles, M.D. Instit. Sc. Paris. Corresp. *Bristol.*
1828. Nov. 20.	Prinsep, James, Esq. 6 *Great Cumberland-street.*
1819. Mar. 11.	* Prout, William, M.D. Coll. Reg. Med. Socius. 40 *Sackville-street.*
1818. April 9.	Prudhoe, Algernon Lord, F.S.A. *Northumberland-house; and Stanwick-park, Darlington, Yorkshire.*
1830. May 27.	Pusey, Philip, Esq. 23 *Hertford-street, May Fair; and Pusey-house, near Farringdon, Berks.*
1803. Feb. 17.	* Rackett, Rev. Thomas, M.A. F.S.A. F.L.S. 48 *Upper Gower-street; and Poole, Dorset.*
1819. June 24.	Ramsbottom, John, Esq. 1 *F, Albany; and Woodside, near Windsor.*
1814. Dec. 15.	Rashleigh, William, Esq. F.L.S. 3 *Cumberland-terrace, Regent's-park; and Menabilly-house, Foy, Cornwall.*
1837. Jan. 19.	† Rastrick, John Urpath, Esq. *Birmingham.*
1838. Feb. 8.	Reade, Rev. Joseph Bancroft, M.A. *Peckham.*
1817. June 12.	Reeves, John, Esq. F.L.S. F.R.A.S. *Clapham.*
1834. Feb. 6.	Reeves, John Russell, Esq. F.L.S. *Clapham.*
1839. Feb. 21.	† Reid, Lieut.-Colonel William, C.B. Royal Engineers, Governor of Bermuda.
1822. Mar. 21.	Rennie, George, Esq. 21 *Whitehall-place.*
1823. June 12.	Rennie, Sir John, Knt. 15 *Whitehall-place.*
1825. Feb. 24.	Richardson, John, M.D. F.R.G.S. F.L.S. Acad. Sc. Nat. Philad., Geogr. Paris

Date of Election.	
	Corresp.—Socc. Hist. Nat. Montreal, Lit. et Phil. Quebec, Hist. Nat. Boston, Socius Honor. *Haslar-hospital, Gosport.*
1820. Mar. 23.	Ricketts, Charles Milner, Esq. F.G.S. *Lima.*
1815. Apr. 27.	Rickman, John, Esq. M.A. 23 *Duke-street, Westminster.*
1839. Apr. 25.	Rigg, Robert, Esq. 2 *Chatham-place, Walworth-road.*
1828. Apr. 17.	Ripon, Frederick John Earl of. *Carlton-gardens.*
1836. Feb. 11.	Robertson, Dr. Archibald. *Northampton.*
1796. Nov. 17.	Rogers, Samuel, Esq. F.S.A. 22 *St. James's-place.*
1779. May 6.	Rogerson, John, M.D.
1815. Mar. 16.	Roget, Peter Mark, M.D.—Secretary.—F.G.S. F.R.A.S. Coll. Reg. Med. Socius. 39 *Bernard-street, Russell-square.*
1824. April 8.	Rokewode, John Gage, Esq. F.S.A. F.L.S. 10 *Old-square, Lincoln's-inn.*
1831. June 9.	Ros, Hon. Frederick De, Captain in the Royal Navy, F.R.A.S. 106 *Piccadilly.*
1834. June 5.	Rose, Sir George. 4 *Hyde-park-gardens.*
1819. April 1.	Roseberry, Archibald John Earl of. 139 *Piccadilly.*
1822. June 13.	Ross, Captain Daniel. *India.*
1828. Dec. 11.	Ross, James Clark, Esq. Captain in the Royal Navy, F.L.S. F.R.A.S. Soc. Reg. Sc. Hafn. Socius.
1837. April 6.	† Royle, John Forbes, M.D. F.L.S. F.G.S. F.R.A.S. Professor of Materia Medica and Therapeutics, King's-college. 20 *Berners-street, Oxford-street.*
1805. Jan. 31.	Rudge, Edward, Esq. F.S.A. F.L.S. F.H.S. F.R.G.S. 44 *Wimpole-street; and Abbey Manor-house, Evesham, Worcestershire.*
1821. June 7.	Russell, Jesse Watts, D.C.L. F.S.S. F.L.S. F.G.S. *Ilam-hall, Staffordshire.*
1818. Apr. 16.	Sabine, Edward, Esq. Major in the Royal Artillery.—Vice-President.—F.R.A.S. Acad. Imp. Sc. Petrop. Socc. Reg. Sc. Norv., et Phil. Nov.-Ebor., Socius.—Acad. Reg. Sc. Brux.: Socc. Reg. Sc. Gotting., et Geogr. Paris., Corresp. *Athenæum and Woolwich.*
1832. Dec. 6.	Sandford, Edward Ayshford, Esq. *Nynehead.*
1833. Apr. 18.	† Saunders, Rev. Augustus Page, M.A. *Charterhouse-school.*
1822. June 27.	Sawbridge, Henry Barne, Esq.
1824. June 17.	Scoresby, Rev. William, B.D. F.R.S.E. Instit. Reg. Sc. Paris. Corresp. *Exeter.*
1800. Jan. 16.	Scott, John Corse, Esq. *Edinburgh.*
1826. Dec. 7.	Scrope, George Poulett, Esq. M.P. F.G.S. 13 *Belgrave-square; and Castle Combe, Chippenham, Wiltshire.*
1824. Jan. 15.	† Scudamore, Sir Charles, Knt. M.D. 6 *Wimpole-street.*
1786. Mar. 9.	Seale, Rev. John Barlow, D.D. F.S.A. *Stisted, near Braintree.*
1821. Feb. 1.	Sedgwick, Rev. Adam, M.A. F.G.S. F.R.A.S. Woodwardian Lecturer, Cambridge. *Cambridge.*
1831. Jan. 13.	Selkirk, Thomas James Earl of. *St. Mary's Isle, Kirkcudbright.*
1814. Nov. 10.	Seppings, Sir Robert, Knt.
1839. May 9.	Sharpey, William, M.D. F.R.S.E. Professor of Anatomy in the University-college, Gower-street.
1831. Apr. 21.	Shee, Sir Martin Archer, Knt. President of the Royal Academy. 32 *Cavendish-square.*
1830. April 1.	Sheepshanks, Rev. Richard, M.A. F.G.S. F.R.A.S. 30 *Woburn-place.*
1824. Mar. 11.	Shuckburgh, Sir Francis, Bart. *Pavilion, Hans-place, Chelsea; and Shuckburgh-park, Warwickshire.*

Date of Election.	
1813. Mar. 11.	Simmons, Richard, Esq. F.S.A. F.L.S. 32 *Welbeck-street.*
1837. Apr. 20.	Skey, Frederic C., Esq. 14 *Charterhouse-square.*
1820. Mar. 23.	Sleath, Rev. John, D.D. F.S.A. *Hertford-street, May-fair.*
1825. May 5.	Smirnove, John, Esq. F.L.S. Soc. Cæs. Nat. Cur. Mosc. Socius. 41 *Wigmore-street.*
1824. May 14.	Smith, Lieut.-Col. Charles Hamilton. *Plymouth.*
1830. Dec. 23.	Smith, James, Esq. F.R.S.E. *Jordan-hill, near Glasgow.*
1837. June 1.	† Smith, John T., Esq. Captain, Madras Engineers. *Madras.*
1803. May 10.	Smith, John Spenser, Esq. F.S.A. *Caen, Normandy.*
1819. Nov. 25.	Smith, Joseph, Esq. F.L.S. 1 *Field-court, Gray's-inn.*
1801. Feb. 26.	Smith, Matthew, Esq. Captain in the Royal Navy. *Blackheath.*
1806. Feb. 13.	Smith, Sir William, Knt.
1811. June 13.	Smith, Admiral Sir William Sidney, K.C.B. *Paris.*
1826. June 15.	Smyth, William Henry, Esq. Captain in the Royal Navy, K.S.F. M.R.I.A. F.S.A. For. Sec. R.A.S.—Instit. Reg. Sc. Paris. Corresp. Acadd. Sc. Neap., et Panorm., Socius. *Spring-garden-house, Cardiff.*
1807. May 7.	* Solly, Richard Horsman, Esq. M.A. F.S.A. F.L.S. F.G.S. 48 *Great Ormond-street.*
1812. May 14.	Solly, Samuel, Esq. 48 *Upper Gower-street.*
1837. Jan. 19.	† Solly, Samuel, Esq. 1 *St. Helen's-place, Bishopsgate-street.*
1823. May 29.	Solly, Samuel Reynolds, Esq. M.A. F.S.A. F.G.S. *Surge-hill, King's Langley, Herts.*
1797. Mar. 9.	Somerset, Edward Adolphus Duke of, K.G. D.C.L. F.S.A. F.L.S.—President of the Royal Institution of Great Britain. *Park-lane.*
1817. Dec. 11.	Somerville, William, M.D. F.R.S.E. F.L.S. F.G.S. *Royal Hospital, Chelsea.*
1821. Feb. 15.	South, Sir James, Knt. F.R.S.E. M.R.I.A. F.L.S. F.R.A.S. Acad. Imp. Sc. Petrop. Socius.—Acad. Reg. Sc. Brux. Corresp. *The Observatory, Camden-hill, Kensington.*
1825. Apr. 14.	Southey, Henry Herbert, M.D. Coll. Reg. Med. Socius. 1 *Harley-street.*
1812. May 28.	Speer, William, Esq. F.S.A. *Great Queen-street, Westminster.*
1834. Apr. 10.	† Spence, William, Esq. F.L.S.
1807. Jan. 8.	* Stanhope, Philip Henry Earl. 14 *Great Stanhope-street; and Chevening-place, Kent.*
1816. June 27.	Stanhope, John Spencer, Esq. Instit. Reg. Sc. Paris. Corresp.
1830. Mar. 11.	Stanley, Edward, Esq. 12 *Lincoln's-inn-fields.*
1790. Apr. 29.	Stanley, Lord John Thomas, F.S.A. *Dover-street, Berkeley-square.*
1803. Apr. 28.	Staunton, Sir George Thomas, Bart. D.C.L. F.S.A. F.L.S. 17 *Devonshire-street, Portland-place.*
1832. Apr. 5.	† Stephens, Archibald John, Esq. M.A. 61 *Chancery-lane; and* 43 *Torrington-square.*
1829. Jan. 15.	Steuart, John Robert, Esq. M.R.A.S. 56 *North Frederick-street, Edinburgh.*
1811. Nov. 21.	Stevenson, William Ford, Esq. F.S.A. *Grande-rue, Passy, near Paris.*
1838. May 3.	Stirling, Edward Hamilton, Esq. *Calcutta.*
1821. Jan. 18.	Stokes, Charles, Esq. F.S.A. F.L.S. F.G.S. F.R.A.S. 4 *Verulam-buildings.*
1823. Nov. 27.	Storey, Anthony Mervin Reeve, Esq. M.A. 85 *Jermyn-street; and Glanusk, Brecon.*
1810. June 7.	Stracey, Sir Edward, Bart. LL.D. *Rackheath-hall, Norfolk.*
1825. Feb. 3.	Strangford, Percy Clinton Sydney Viscount, G.C.B. G.C.H. D.C.L. F.S.A. 68 *Harley-street.*
1821. Mar. 8.	Strangways, Hon. William Thomas Horner Fox. 18 *Clifford-street; and Abbotsbury, Dorsetshire.*
1832. June 7.	† Stratford, William Samuel, Esq. Lieutenant in the Royal Navy. F.R.A.S. Superintend-

Date of Election.	
	ent of the Nautical Almanac. 3 *Verulam-buildings, Gray's-inn; and* 6 *Notting-hill-square, Kensington.*
1830. May 6.	Stratton, Major-General Sir Joseph, Knt. C.B. F.R.S.E.
1807. Feb. 5.	Stratton, George Frederick, Esq. LL.D. F.S.A. *Tew-park, Deddington.*
1796. Nov. 17.	Sumner, George Holme, Esq. F.S.A. *Hatchlands, Guildford, Surrey.*
1828. Mar. 13.	Sutherland, Alexander Robert, M.D. F.G.S. 1 *Parliament-street; and Hermitage, Brompton.*
1820. Dec. 14.	Swainson, William, Esq. F.L.S. Soc. Hist. Nov.-Ebor. Socius.—Soc. Hist. Nat. Paris. Corresp. *Tittenhanger-green, near St. Alban's.*
1818. Feb. 26.	Swinburne, Sir John Edward, Bart. F.S.A. 18 *Grosvenor-place.*
1839. Mar. 14.	† Swanston, Clement Tudway, Esq. F.S.A. *Chancery-lane.*
1834. Feb. 6.	† Sykes, Lieut.-Colonel William Henry, F.L.S. F.G.S. M.R.A.S. 47 *Albion-street, Hyde-park.*
1839. Apr. 25.	† Sylvester, James Joseph, Esq. F.R.A.S. Professor of Natural Philosophy and Astronomy in the University-college, Gower-street.
1835. June 4.	† Symonds, Sir William, K.H. Captain in the Royal Navy. 4 *Somerset-place.*
1813. May 6.	Talbot, Charles Chetwynd Earl, K.P. F.S.A. 71 *Grosvenor-street; and Ingestrie-hall, near Stafford.*
1831. Mar. 17.	Talbot, Christopher Rice Mansel, Esq. *Belgrave-square; and Margam, Glamorganshire.*
1831. Mar. 17.	Talbot, William Henry Fox, Esq. 31 *Sackville-street; and Lacock-abbey, near Chippenham.*
1835. Feb. 5.	† Tattam, Rev. Henry, M.A. M.R.S.L. *Bedford.*
1825. May 5.	Taylor, John, Esq. Treas. G.S. 12 *Bedford-row.*
1826. Feb. 16.	Taylor, George Watson, Esq. F.S.A.
1836. Jan. 21.	† Taylor, Rev. William. *York.*
1834. June 5.	Teignmouth, Charles John Lord, D.C.L. 19 *Portland-place.*
1829. Feb. 19.	Tennyson d'Eyncourt, Right Hon. Charles, M.P. F.S.A. 10 *Park-place, St. James's.*
1833. Dec. 5.	Terry, Charles, Esq. *Shoe-lane.*
1806. Jan. 16.	Thomas, Honoratus Leigh, Esq. 12 *Leicester-place.*
1828. Nov. 20.	Thompson, Lieut.-Colonel Thomas Perronet, M.A. *North-end, Hampstead.*
1821. Dec. 20.	Thomson, James, Esq. *Primrose, near Clitheroe.*
1824. June 3.	Thomson, John, M.D. F.R.S.E. 80 *George-street, Edinburgh.*
1811. Mar. 28.	Thomson, Thomas, M.D., Regius Professor of Chemistry, Glasgow, F.R.S.E. F.L.S. F.G.S. *Glasgow.*
1810. June 7.	Thornton, Right Hon. Sir Edward, G.C.B. *Wembury-house, Plymouth.*
1834. Apr. 10.	† Thornton, Henry Sykes, Esq. M.A. *Battersea-rise, Surrey.*
1839. May 30.	† Thorp, The Venerable Charles, D.D. Archdeacon of Durham and Warden of the University of Durham.
1793. Apr. 18.	Tighe, Robert Stearne, Esq. F.S.A.
1835. Apr. 2.	Tite, William, Esq. F.S.A. 25 *Upper Bedford-place.*
1838. Feb. 8.	† Todd, Robert Bently, M.D. Professor of Physiology and General Anatomy, King's-college, London. 26 *Parliament-street.*
1821. Mar. 22.	Tooke, Thomas, Esq. 31 *Spring-gardens.*
1818. Mar. 12.	Tooke, William, Esq. M.R.S.L. 12 *Russell-square.*
1818. Dec. 17.	* Torrens, Lieut.-Colonel Robert. 6 *Adelphi-terrace.*

Date of Election.	
1812. Dec. 17.	* Towneley, Peregrine Edward, Esq. Trust. Brit. Mus. F.S.A. 7 *Park-street, Westminster; and Towneley-hall, near Burnley, Lancashire.*
1822. Nov. 7.	Townley, George, Esq. 5 *L, Albany.*
1823. May 29.	Traherne, Rev. John Montgomery, M.A. F.L.S. F.G.S. *St. Hilary, near Cowbridge, Glamorganshire.*
1815. Nov. 16.	Travers, Benjamin, Esq. 12 *Bruton-street.*
1822. Nov. 14.	Tulk, Charles Augustus, Esq. F.S.A. 19 *Duke-street, Westminster.*
1835. Feb. 5.	† Tupper, Martin, Esq. F.G.S. 5 *New Burlington-street.*
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1831. Mar. 17.	Turnbull, Rev. Thomas Smith, M.A. F.G.S. *Caius-college, Cambridge.*
1821. May 24.	Turner, Charles Hampden, Esq. F.L.S. F.G.S. 16 *Bruton-street; and Rook's Nest, Godstone, Surrey.*
1802. Dec. 9.	Turner, Dawson, Esq. Hon. M.R.I.A. F.S.A. F.L.S. M.R.S.L. Acadd. Cæs. Nat. Cur. et Reg. Sc. Holm. Socius. *Yarmouth.*
1815. Dec. 21.	Turner, Samuel, Esq. *Liverpool.*
1839. May 9.	† Turnor, Rev. Charles, M.A. F.S.A. F.R.A.S. *Cheltenham.*
1838. Apr. 5.	† Tuson, Edward William, Esq. F.L.S. 10 *Russell-place.*
1838. Feb. 8.	† Tweedie, Alexander, M.D. *Montague-place, Bedford-square.*
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1838. Mar. 15.	† Twiss, Travers, Esq. B.C.L. F.G.S. *University-college, Oxford.*
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1834. Jan. 9.	† Tyrconnel, John Delaval Earl of. *Kipon-park, Yorkshire.*
1821. Dec. 13.	Ure, Andrew, M.D. F.R.A.S. 13 *Charlotte-street, Bedford-square.*
1813. June 24.	Vaughan, William, Esq. F.L.S. F.R.A.S. 70 *Fenchurch-street.*
1830. May 6.	Vetch, Captain James. 7 *Crane-court, Fleet-street.*
1826. Feb. 23.	† Vigors, Nicholas Aylward, Esq. D.C.L. M.A. M.P. M.R.I.A. F.S.A. F.L.S. 16 *Chester-terrace, Regent's-park.*
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1826. June 8.	Vyvyan, Sir Richard Rawlinson, Bart. 87 *Pall Mall; and Trelowarren, Cornwall.*
1828. Apr. 17.	Walker, James, Esq. F.R.S.E. 23 *Great George-street, Westminster.*
1831. Mar. 3.	Walker, Rev. Robert, M.A. *Wadham-college, Oxford.*
1830. April 1.	Wall, Charles Baring, Esq. M.A. M.P. F.S.A. M.R.S.L. 44 *Berkeley-square; and Normancourt, near Stockbridge, Hampshire.*
1829. Mar. 12.	Wallich, Nathaniel, M. et Ph. D. F.R.S.E. F.L.S. F.G.S. M.R.A.S. Inst. Reg. Sc. Paris., et Acad. Reg. Sc. Berolin., Corresp.—Soc. Reg. Sc. Hafn. Socius. *India.*
1819. Nov. 11.	Walter, Rev. Henry, B.D. *Hasilbury Bryan, Dorsetshire.*
1837. May 25.	† Walton, Rev. William. *Allenheads, Northumberland.*
1809. Feb. 16.	Warburton, Henry, Esq. M.A. M.P. V.P.G.S. 45 *Cadogan-place, Sloane-street.*
1834. Apr. 10.	Warburton, John, M.D. Coll. Reg. Med. Socius. 5 *Clifford-street.*
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1830. Dec. 9.	Warren, Rev. John, M.A. *Graveley, Cambridgeshire.*
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1815. June 8.	Warrender, Right Hon. Sir George, Bart. F.R.S.E. 22 *Albemarle-street.*
1834. Feb. 6.	† Waterhouse, John, jun. Esq. *Halifax, Yorkshire.*
1818. Nov. 12.	Watson, Sir Frederick Beilby, K.C.H. F.S.A.
1820. Dec. 7.	Watt, James, Esq. *Aston-hall, Birmingham.*

Date of Election.	
1827. May 24.	† Wavell, Major-General Arthur Goodall, K.F. K.C.S.
1826. Mar. 9.	Weaver, Thomas, Esq. M.R.I.A. F.G.S. *Woodlands, Wrington.*
1822. Mar. 21.	Webb, Frederick, Esq. F.S.A. *Langham-place, Brighton.*
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1837. May 25.	† Westmacott, Richard, Esq. F.G.S. 21 *Wilton-place, Belgrave-square.*
1824. Dec. 16.	Wetherell, Sir Charles, Knt. D.C.L. 5 *Stone-buildings, Lincoln's-inn.*
1814. June 9.	Weyland, John, Esq. 52 *Charles-street, Berkeley-square; and Woodrising-hall, Norfolk.*
1836. Jan. 21.	† Wheatstone, Charles, Esq. Professor of Experimental Philosophy, King's College, London. 20 *Conduit-street.*
1820. Apr. 13.	Whewell, Rev. William, B.D. F.S.A. F.G.S. F.R.A.S. *Trinity-college, Cambridge.*
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1835. April. 2.	† Williams, Charles J. B., M.D. Professor of Physics in the University-college, London. 7 *Holles-street, Cavendish-square.*
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1830. Apr. 22.	Willis, Rev. Robert, M.A. F.G.S. Jacksonian Professor of Nat. and Exp. Philosophy, *Cambridge.*
1812. May 7.	Wilmot, Sir John Eardley Eardley, Bart. D.C.L. M.P. F.S.A. F.L.S. *Athenæum; and Berkswell-park, near Coventry.*
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1796. Apr. 28.	Wilson, Glocester, Esq. *Hastings.*
1834. Apr. 10.	Wilson, Horace Hayman, Esq. M.R.A.S. Boden Professor of Sanscrit in the University of Oxford. 6 *York-place, Portman-square; and Oxford.*
1831. Feb. 24.	Wilson, Sir Isaac, Knt. M.D. F.R.S.Ed. *High-street, Fareham, Hants.*
1834. June 5.	Witt, George, M.D. *Bedford.*
1813. Feb. 25.	Wix, Rev. Samuel, M.A. F.S.A. *Rectory-house, St. Bartholomew's the Less.*
1810. July 12.	Wix, William, Esq. *Rectory-house, St. Bartholomew's the Less; and Tunbridge-wells.*
1829. Feb. 26.	Wollaston, Alexander Luard, Esq. M.B. F.R.A.S.
1812. Dec. 24.	* Wood, William, Esq. F.L.S. 39 *Tavistock-street, Covent-garden.*
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1814. May 5.	Yelloly, John, M.D. F.G.S. Soc. Phil. Nov.-Ebor. Socius. *Woodton-hall, Norfolk.*

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Jens Jacob Berzelius	*Stockholm.*	1813.
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Friedrich Georg Wilhelm Struve	*Dorpat.*	1827.
Friedrich Tiedemann	*Heidelberg.*	1832.
Le baron Thénard	*Paris.*	1824.
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*		

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LIST

OF THE COUNCILS

OF

THE ROYAL SOCIETY,

COMMENCING WITH THE YEAR 1800.

The election of the Council takes place at the Anniversary Meeting on St. Andrew's day in each year.

1799—1800.

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1800—1801.

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1803—1804.

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1807—1808.

The Right Hon. Sir Joseph Banks, Bart., K.B., *President.*

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1808—1809.

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1810—1811.

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1811—1812.

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Edward Rudge, Esq.
Sir George Thomas Staunton, Bart.
Smithson Tennant, Esq.
Rev. William Tooke.
William Charles Wells, M.D.
Giffin Wilson, Esq.

1814—1815.

The Right Hon. Sir JOSEPH BANKS, Bart., K.B., *President.*

Samuel Lysons, Esq., *Treasurer & V.P.*
William Hyde Wollaston, M.D. } *Secretaries.*
Taylor Combe, Esq. }
Thomas Young, M.D., *Foreign Secretary.*

William Allen, Esq.
Sir Charles Blagden, Knt.
William Blake, Esq.
Rev. Charles Burney, D.D.
Lord Bishop of Carlisle, *V.P.*
Earl of Charleville.
Davies Giddy, Esq.
Sir Everard Home, Bart., *V.P.*
James Horsburgh, Esq.
Alexander Marcet, M.D.
Earl of Morton, K.T., *V.P.*
Thomas Murdoch, Esq.
John Pond, Esq., A.R.
Earl of Selkirk.
Henry Warburton, Esq.
William Charles Wells, M.D.

1815—1816.

The Right Hon. Sir JOSEPH BANKS, Bart., K.B., *President.*

Samuel Lysons, Esq., *Treasurer & V.P.*
William Hyde Wollaston, M.D. } *Secretaries.*
Taylor Combe, Esq. }
Thomas Young, M.D., *Foreign Secretary.*

John Barrow, Esq.
Mark Beaufoy, Esq.
Sir Charles Blagden, Knt.
Henry Browne, Esq.
Lord Bishop of Carlisle, *V.P.*
Sir Humphry Davy, Knt.
Davies Giddy, Esq.
Earl of Hardwicke, K.G.
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Edward Howard, Esq.
John Latham, M.D.
Thomas James Mathias, Esq.
Earl of Morton, K.T., *V.P.*
Sir John Nicholl, Knt.
John Pond, Esq., A.R.
Earl of Winchilsea, K.G.

1816—1817.

The Right Hon. Sir JOSEPH BANKS, Bart., K.B., *President.*

Samuel Lysons, Esq., *Treasurer & V.P.*
Taylor Combe, Esq. } *Secretaries.*
William Thomas Brande, Esq. }
Thomas Young, M.D., *Foreign Secretary.*

John Barrow, Esq.
Lord Bishop of Carlisle, *V.P.*
John George Children, Esq.
John Wilson Croker, Esq.
Sir Humphry Davy, Knt.
Sir Everard Home, Bart., *V.P.*
Charles Konig, Esq.
Alexander MacLeay, Esq.
Alexander Marcet, M.D.
Earl of Morton, K.T., *V.P.*
Col. William Mudge.
William Hasledine Pepys, Esq.
John Pond, Esq., A.R.
Earl Spencer, K.G.
Sir John Thomas Stanley, Bart.
William Hyde Wollaston, M.D.

1817—1818.

The Right Hon. Sir JOSEPH BANKS, Bart., K.G.B., *President.*

Samuel Lysons, Esq., *Treasurer & V.P.*
Taylor Combe, Esq. } *Secretaries.*
William Thomas Brande, Esq. }
Thomas Young, M.D., *Foreign Secretary.*

Earl of Aberdeen, K.T.	Right Hon. Charles Long.
Lord Bishop of Carlisle, *V.P.*	Earl of Morton, K.T., *V.P.*
Sir Humphry Davy, Knt.	John Pond, Esq., A.R.
Davies Gilbert, Esq.	John Reeves, Esq.
Charles Hatchett, Esq.	Richard Anthony Salisbury, Esq.
Sir Everard Home, Bart., *V.P.*	Duke of Somerset.
Captain Henry Kater.	Gloucester Wilson, Esq.
Lord Bishop of London.	William Hyde Wollaston, M.D.

1818—1819.

The Right Hon. Sir JOSEPH BANKS, Bart., K.G.B., *President.*

Samuel Lysons, Esq., *Treasurer & V.P.*
Taylor Combe, Esq. } *Secretaries.*
William Thomas Brande, Esq. }
Thomas Young, M.D., *Foreign Secretary.*

James Peter Auriol, Esq.	Maj.-Gen. Sir J. W. Gordon, K.C.B.
Robert Bingley, Esq.	Sir Everard Home, Bart., *V.P.*
Lord Bishop of Carlisle, *V.P.*	Sir Alexander Johnston, Knt.
Sir Thomas Gery Cullum, Bart.	Earl of Morton, K.T., *V.P.*
Earl of Darnley.	Rev. Robert Nares.
Samuel Davis, Esq.	John Pond, Esq., A.R.
Sir Humphry Davy, Bart.	Sir George Thomas Staunton, Bart.
Lord Glenbervie.	William Hyde Wollaston, M.D.

1819—1820.

The Right Hon. Sir JOSEPH BANKS, Bart., G.C.B., *President.**

Davies Gilbert, Esq., *Treasurer & V.P.*
Taylor Combe, Esq. } *Secretaries.*
William Thomas Brande, Esq. }
Thomas Young, M.D., *Foreign Secretary.*

William Blake, Esq.	Captain Henry Kater.
Earl Brownlow.	Daniel Moore, Esq.
Lord Bishop of Carlisle, *V.P.*	Right Hon. Sir John Nicholl, Knt.
Earl of Charleville.	John Pond, Esq., A.R.
Alexander Crichton, M.D.	Rev. Thomas Rackett.
Maj.-Gen. Sir J. W. Gordon, Bart.	Sir George Thomas Staunton, Bart.
Sir Benjamin Hobhouse, Bart.	William Hyde Wollaston, M.D.
Sir Everard Home, Bart., *V.P.*	Right Hon. Charles Yorke.

* On the decease of Sir Joseph Banks, Dr. Wollaston was, on the 29th of June, elected, by the Council, President, until the next Anniversary.

1820—1821.

Sir HUMPHRY DAVY, Bart., *President.*

Davies Gilbert, Esq., *Treasurer & V.P.*
Taylor Combe, Esq. } *Secretaries.*
William Thomas Brande, Esq. }
Thomas Young, M.D., *Foreign Secretary.*

Edward Ash, M.D.	Charles Hatchett, Esq., *V.P.*
William Blake, Esq.	John F. W. Herschel, Esq., M.A.
Earl Brownlow.	Sir Everard Home, Bart., *V.P.*
Lord Bishop of Carlisle, *V.P.*	Captain Henry Kater.
John George Children, Esq.	Joseph Planta, Esq.
Sir George Clerk, Bart.	John Pond, Esq., A.R.
Henry Thomas Colebrooke, Esq.	Earl Spencer, K.G.
John Wilson Croker, Esq., LL.D.	William H. Wollaston, M.D., *V.P.*

1821—1822.

Sir HUMPHRY DAVY, Bart., *President.*

Davies Gilbert, Esq., *Treasurer & V.P.*
Taylor Combe, Esq. } *Secretaries.*
William Thomas Brande, Esq. }
Thomas Young, M.D., *Foreign Secretary.*

Earl of Aberdeen, K.T.	Sir Everard Home, Bart., *V.P.*
Matthew Baillie, M.D.	James Ivory, Esq., M.A.
John Barrow, Esq.	The Marquis of Lansdowne.
Benjamin Collins Brodie, Esq.	Alexander Marcet, M.D.
Lord Bishop of Carlisle, *V.P.*	Thomas Murdoch, Esq.
William Richard Hamilton, Esq.	John Pond, Esq., A.R.
Charles Hatchett, Esq., *V.P.*	Sir Robert Seppings, Knt.
John F. W. Herschel, Esq., M.A.	William H. Wollaston, M.D., *V.P.*

1822—1823.

Sir HUMPHRY DAVY, Bart., *President.*

Davies Gilbert, Esq., *Treasurer & V.P.*
Taylor Combe, Esq. } *Secretaries.*
William Thomas Brande, Esq. }
Thomas Young, M.D., *Foreign Secretary.*

Charles Babbage, Esq., M.A.	John F. W. Herschel, Esq., M.A.
Sir Gilbert Blane, Bart., M.D.	Sir Everard Home, Bart., *V.P.*
Lord Bishop of Carlisle, *V.P.*	Charles Hutton, LL.D.
Lord Colchester.	Captain Henry Kater.
John Wilson Croker, Esq., LL.D.	William Hasledine Pepys, Esq.
Earl of Darnley.	John Pond, Esq., A.R.
Sir Henry Halford, Bart.	Joseph Sabine, Esq.
Charles Hatchett, Esq., *V.P.*	William H. Wollaston, M.D., *V.P.*

1823—1824.

Sir HUMPHRY DAVY, Bart., *President.*

Davies Gilbert, Esq., *Treasurer & V.P.*
Taylor Combe, Esq. } *Secretaries.*
William Thomas Brande, Esq. }
Thomas Young, M.D., *Foreign Secretary.*

William Allen, Esq.
Lord Bishop of Carlisle, *V.P.*
Major Thomas Colby, R.E.
John Wilson Croker, Esq., LL.D.
Charles Hatchett, Esq., *V.P.*
Sir Everard Home, Bart., *V.P.*
James Ivory, Esq., M.A.
Sir James MacGrigor, Knt.
William Marsden, Esq.
William George Maton, M.D.
Duke of Norfolk.
John Pond, Esq., A.R.
Edward Rudge, Esq.
William Sotheby, Esq.
Henry Warburton, Esq.
William H. Wollaston, M.D., *V.P.*

1824—1825.

Sir HUMPHRY DAVY, Bart., *President.*

Davies Gilbert, Esq., *Treasurer & V.P.*
William Thomas Brande, Esq. } *Secretaries.*
John F. W. Herschel, Esq. }
Thomas Young, M.D., *Foreign Secretary.*

William Babington, M.D.
Francis Baily, Esq.
Lord Bishop of Carlisle, *V.P.*
John George Children, Esq.
Major Thomas Colby, R.E.
John Wilson Croker, Esq., LL.D.
Charles Hatchett, Esq., *V.P.*
Sir Everard Home, Bart., *V.P.*
Captain Henry Kater.
Thomas Andrew Knight, Esq.
Alexander MacLeay, Esq.
John Pond, Esq., A.R.
Sir Thomas S. Raffles, Knt.
Duke of Somerset.
William H. Wollaston, M.D., *V.P.*
Viscount Dudley and Ward.

1825—1826.

Sir HUMPHRY DAVY, Bart., *President.*

Davies Gilbert, Esq., *Treasurer & V.P.*
William Thomas Brande, Esq. } *Secretaries.*
John F. W. Herschel, Esq. }
Thomas Young, M.D., *Foreign Secretary.*

John Barrow, Esq.
Francis Baily, Esq.
John Bostock, M.D.
Lord Bishop of Carlisle, *V.P.*
Sir Astley Paston Cooper, Bart.
Benjamin Gompertz, Esq.
Stephen Groombridge, Esq.
Sir Everard Home, Bart., *V.P.*
Sir Abraham Hume, Bart.
Captain Henry Kater.
Daniel Moore, Esq.
Earl of Mount Edgecombe.
John Pond, Esq., A.R.
Peter Mark Roget, M.D.
James South, Esq.
William H. Wollaston, M.D., *V.P.*

1826—1827.

Sir HUMPHRY DAVY, Bart., *President.**

Davies Gilbert, Esq., *Treasurer & V.P.*
John F. W. Herschel, Esq. } *Secretaries.*
John George Children, Esq. }
Thomas Young, M.D., *Foreign Secretary.*

John Abernethy, Esq.
Charles Babbage, Esq.
John Barrow, Esq.
Captain Francis Beaufort, R.N.
Robert Brown, Esq.
Lord Bishop of Carlisle, *V.P.*
Charles Hatchett, Esq.
Sir Everard Home, Bart., *V.P.*
Captain Henry Kater.
Aylmer Bourke Lambert, Esq.
Viscount Lowther.
George Pearson, M.D.
John Pond, Esq., A.R.
William Prout, M.D.
James South, Esq.
William H. Wollaston, M.D., *V.P.*

* On the resignation of the President (Nov. 6th, 1827), Davies Gilbert, Esq. was elected President *pro tempore*. (See Council Minutes, vol. x. p. 300.)

1827—1828.

DAVIES GILBERT, Esq., *President.*

Captain Henry Kater, *Treasurer & V.P.*
Peter Mark Roget, M.D. } *Secretaries.*
Captain Edward Sabine, R.A. }
Thomas Young, M.D., *Foreign Secretary.*

Francis Baily, Esq.
Captain Francis Beaufort, R.N.
Rev. William Buckland, D.D.
John George Children, Esq.
Lord Colchester.
John Wilson Croker, Esq., LL.D.
Sir Humphry Davy, Bart.
William Henry Fitton, M.D.
Rev. Edmund Goodenough.
John Guillemard, Esq.
John F. W. Herschel, Esq., *V.P.*
Sir Everard Home, Bart., *V.P.*
John Ayrton Paris, M.D.
John Pond, Esq., A.R.
William Prout, M.D.
William H. Wollaston, M.D., *V.P.*

1828—1829.

DAVIES GILBERT, Esq., *President.*

Captain Henry Kater, *Treasurer & V.P.*
Peter Mark Roget, M.D. } *Secretaries.*
Captain Edward Sabine, R.A. }
Thomas Young, M.D., *Foreign Secretary.*

Francis Baily, Esq.
Charles Bell, Esq.
Robert Brown, Esq.
Francis Chantrey, Esq.
Right Hon. Sir G. Cockburn.
Michael Faraday, Esq.
William Henry Fitton, M.D.
Charles Hatchett, Esq.
John F. W. Herschel, Esq., *V.P.*
Sir Everard Home, Bart., *V.P.*
Marquis of Lansdowne.
Right Hon. Robert Peel.
John Pond, Esq., A.R.
Rev. Adam Sedgwick.
Henry Warburton, Esq.
William Hyde Wollaston, M.D.

1829—1830.

DAVIES GILBERT, Esq., *President.*

Captain Henry Kater, *Treasurer & V.P.*
Peter Mark Roget, M.D. } *Secretaries.*
Captain E. Sabine, R.A. }

Peter Barlow, Esq.
Charles Bell, Esq.
William Thomas Brande, Esq.
Robert Brown, Esq.
John Frederic Daniell, Esq.
Henry Ellis, Esq.
Michael Faraday, Esq.
Sir John Franklin, Knt.
Sir Everard Home, Bart., *V.P.*
Sir Thomas Lawrence, Knt.
Viscount Melville.
Right Hon. Sir G. Murray.
Alexander Wilson Philip, M.D.
John Pond, Esq., A.R.
George Rennie, Esq.
Rev. Adam Sedgwick.
Henry Warburton, Esq.

William Thomas Brande, Esq. was elected Foreign Secretary by the Council on the 4th February, 1830. (See Council Book, vol. xi. p. 78.)

1830—1831.

H.R.H. the DUKE OF SUSSEX, *President.*

John William Lubbock, Esq., M.A., *Treasurer & V.P.*
Peter Mark Roget, M.D. } *Secretaries.*
John George Children, Esq. }

Peter Barlow, Esq.
John Barrow, Esq.
William Cavendish, Esq.
Sir Astley Cooper, Bart., *V.P.*
Henry Ellis, Esq.
Michael Faraday, Esq.
Colonel Fitzclarence.
Davies Gilbert, Esq., *V.P.*
Captain Henry Kater.
Viscount Melville.
Right Hon. Sir G. Murray.
Rev. George Peacock.
Right Hon. Sir Robert Peel, Bart.
Alexander Wilson Philip, M.D.
John Pond, Esq., A.R.
George Rennie, Esq., *V.P.*
Nicholas A. Vigors, Esq.

Charles Konig, Esq. was elected Foreign Secretary by the Council on the 16th December, 1830. (See Council Book, vol. xi. p. 145.)

1831—1832.

H.R.H. the DUKE OF SUSSEX, K.G., *President.*

John William Lubbock, Esq., M.A., *Treasurer & V.P.*
Peter Mark Roget, M.D. } *Secretaries.*
John George Children, Esq. }
Charles Konig, Esq., *Foreign Secretary.*

Peter Barlow, Esq.
John Bostock, M.D., *V.P.*
Rev. William Buckland, D.D., *V.P.*
Samuel Hunter Christie, Esq., M.A.
Rev. Henry Coddington.
Charles Daubeny, M.D.
George Dollond, Esq.
Davies Gilbert, Esq., *V.P.*
Joseph Henry Green, Esq.
William George Maton, M.D., *V.P.*
Roderick I. Murchison, Esq.
Rev. George Peacock.
George Rennie, Esq., *V.P.*
Captain W. H. Smyth.
Nicholas A. Vigors, Esq.
Rev. William Whewell.

1832—1833.

H.R.H. the DUKE OF SUSSEX, K.G., *President.*

John William Lubbock, Esq., M.A., *Treasurer & V.P.*
Peter Mark Roget, M.D. } *Secretaries.*
John George Children, Esq. }
Charles Konig, Esq., *Foreign Secretary.*

Francis Baily, Esq., *V.P.*
Captain Francis Beaufort, R.N.
Mark Isambard Brunel, Esq., *V.P.*
Rev. William Buckland, D.D., *V.P.*
Samuel Hunter Christie, Esq., M.A.
William Clift, Esq.
Rev. James Cumming, *V.P.*
Benjamin Gompertz, Esq.
Joseph Henry Green, Esq.
George Bellas Greenough, Esq.
William George Maton, M.D., *V.P.*
Roderick I. Murchison, Esq.
William H. Pepys, Esq.
Stephen Peter Rigaud, Esq.
Rev. Richard Sheepshanks.
Rev. William Whewell.

1833—1834.

H.R.H. the DUKE OF SUSSEX, K.G., *President.*

John William Lubbock, Esq., M.A., *Treasurer & V.P.*
Peter Mark Roget, M.D. } *Secretaries.*
John George Children, Esq. }
Charles Konig, Esq., *Foreign Secretary.*

Francis Baily, Esq., *V.P.*
Peter Barlow, Esq.
William Thomas Brande, Esq.
Benjamin Collins Brodie, Esq., *V.P.*
Mark Isambard Brunel, Esq., *V.P.*
William Clift, Esq.
Rev. James Cumming, *V.P.*
Michael Faraday, Esq.
Davies Gilbert, Esq., *V.P.*
George Bellas Greenough, Esq.
Rev. Philip Jennings.
Rev. George Peacock.
William H. Pepys, Esq.
Rev. Baden Powell.
Rev. Adam Sedgwick.
Captain W. H. Smyth.

1834—1835.

H.R.H. the DUKE OF SUSSEX, K.G., *President.*

John William Lubbock, Esq., M.A., *Treasurer & V.P.*
Peter Mark Roget, M.D. } *Secretaries.*
John George Children, Esq. }
Charles Konig, Esq., *Foreign Secretary.*

Charles Frederick Barnwell, Esq.
Henry Thomas De La Beche, Esq.
William Thomas Brande, Esq., *V.P.*
Sir Benjamin Brodie, Bart., *V.P.*
Michael Faraday, Esq.
Henry Holland, M.D.
Rev. Philip Jennings, D.D., *V.P.*
Charles Lyell, Esq.
Herbert Mayo, Esq.
Roderick I. Murchison, Esq.
Lord Oxmantown.
Rev. George Peacock, *V.P.*
Rev. Baden Powell.
Sir John Rennie, *V.P.*
Edward Turner, M.D.
Rev. William Whewell.

1835—1836.

H.R.H. the Duke of Sussex, K.G., *President.*

Francis Baily, Esq., *Treasurer & V.P.*
Peter Mark Roget, M.D. } *Secretaries.*
John George Children, Esq. }
Charles Konig, Esq., *Foreign Secretary.*

William Allen, Esq.
Rev. William Buckland, D.D.
Samuel Hunter Christie, Esq., M.A.
Rev. James Cumming.
Davies Gilbert, Esq., *V.P.*
Joseph Henry Green, Esq.
Henry Holland, M.D., *V.P.*
William Lawrence, Esq.
John W. Lubbock, Esq., M.A.
Herbert Mayo, Esq.
Roderick I. Murchison, Esq., *V.P.*
Rev. Robert Murphy.
Sir John Rennie, *V.P.*
Captain W. H. Smyth.
Edward Turner, M.D.
Rev. William Whewell, *V.P.*

1836—1837.

H.R.H. the Duke of Sussex, K.G., *President.*

Francis Baily, Esq., *Treasurer & V.P.*
Peter Mark Roget, M.D. } *Secretaries.*
John George Children, Esq. }
Charles Konig, Esq., *Foreign Secretary.*

George Biddle Airy, Esq., A.R.
William Allen, Esq.
John Bostock, M.D.
Earl of Burlington, *V.P.*
Samuel Hunter Christie, Esq., M.A.
Viscount Cole, M.P.
Joseph Henry Green, Esq.
George Bellas Greenough, Esq.
William Lawrence, Esq., *V.P.*
John Lindley, Phil.D.
John W. Lubbock, Esq., M.A., *V.P.*
Rev. George Peacock.
William H. Pepys, Esq.
Rev. Adam Sedgwick, *V.P.*
Captain W. H. Smyth, *V.P.*
William H. Fox Talbot, Esq.

1837—1838.

H.R.H. the Duke of Sussex, K.G., *President.*

Francis Baily, Esq., *Treasurer & V.P.*
Peter Mark Roget, M.D. } *Secretaries.*
Samuel Hunter Christie, Esq., M.A. }
Captain W. H. Smyth, *Foreign Secretary.*

John Bostock, M.D.
Earl of Burlington, *V.P.*
John George Children, Esq., *V.P.*
John Frederic Daniell, Esq.
Sir Philip Grey Egerton, Bart.
Davies Gilbert, Esq., *V.P.*
Charles Konig, Esq.
Marquis of Northampton, *V.P.*
Rev. George Peacock.
William H. Pepys, Esq.
Stephen Peter Rigaud, Esq., *V.P.*
John Forbes Royle, M.D.
Benjamin Travers, Esq.
James Walker, Esq.
Charles Wheatstone, Esq.
Rev. William Whewell.

1838—1839.

The Marquis of Northampton, *President.*

John William Lubbock, Esq., M.A., *Treasurer & V.P.*
Peter Mark Roget, M.D. } *Secretaries.*
Samuel Hunter Christie, Esq., M.A. }
Captain W. H. Smyth, *Foreign Secretary.*

H.R.H. Duke of Sussex, K.G., *V.P.*
Francis Baily, Esq., *V.P.*
John George Children, Esq., *V.P.*
John Frederic Daniell, Esq.
C. G. B. Daubeny, M.D.
Thomas Galloway, Esq.
Thomas Graham, Esq.
Sir J. F. W. Herschel, Bt., M.A., *V.P.*
Francis Kiernan, Esq.
John Forbes Royle, M.D., *V.P.*
Rev. Adam Sedgwick.
Robert Bently Todd, M.D.
Charles Wheatstone, Esq.
Rev. William Whewell.
Rev. Robert Willis.
George Rennie, Esq.

1839—1840.

The Marquis of Northampton, *President.*

John William Lubbock, Esq., M.A., *Treasurer & V.P.*
Peter Mark Roget, M.D. } *Secretaries.*
Samuel Hunter Christie, Esq., M.A. }
John Frederic Daniell, Esq., *Foreign Secretary.*

Sir John Barrow, Bart., *V.P.*
Francis Baily, Esq., *V.P.*
Thomas Bell, Esq.
John Davy, M.D.
Bryan Donkin, Esq.
Edward Forster, Esq.
Thomas Galloway, Esq., M.A.
Thomas Graham, Esq.
Sir J. F. W. Herschel, Bt., M.A., *V.P.*
Francis Kiernan, Esq.
John Lindley, Esq., Phil.D.
Richard Owen, Esq.
Richard Phillips, Esq.
Major Edward Sabine, R.A., *V.P*
Robert Bently Todd, M.D.
John Taylor, Esq.

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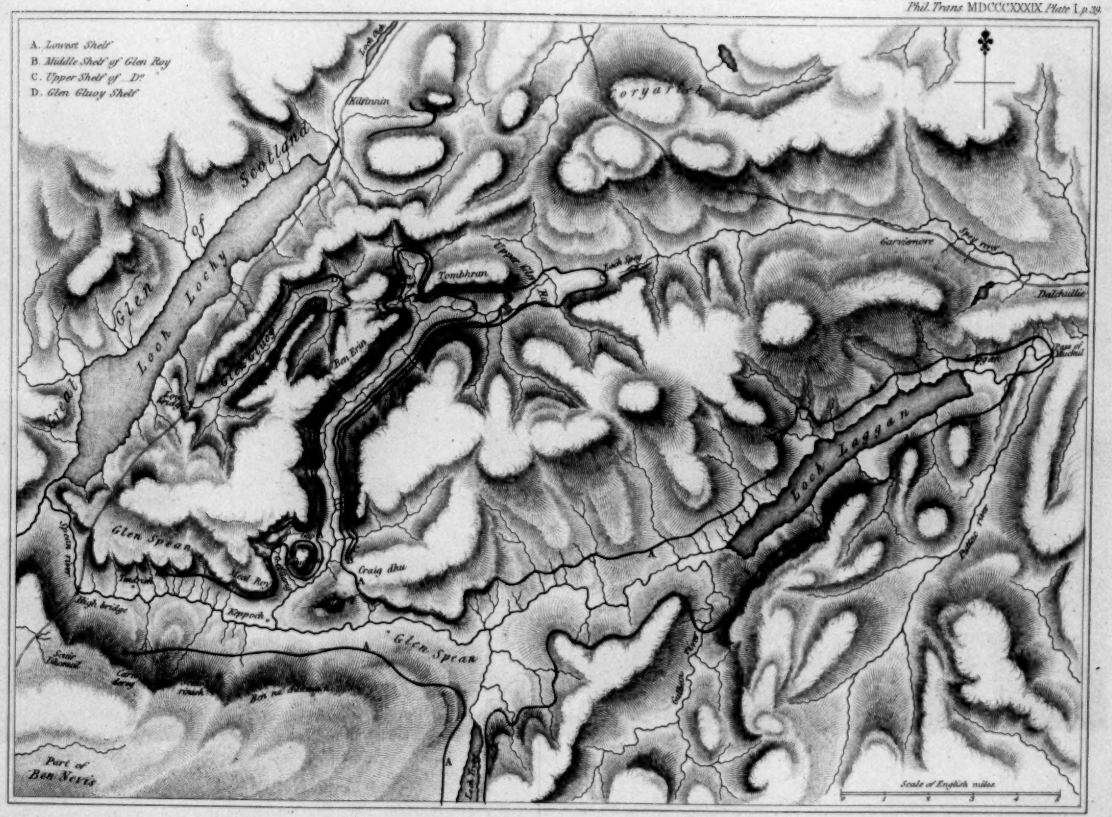
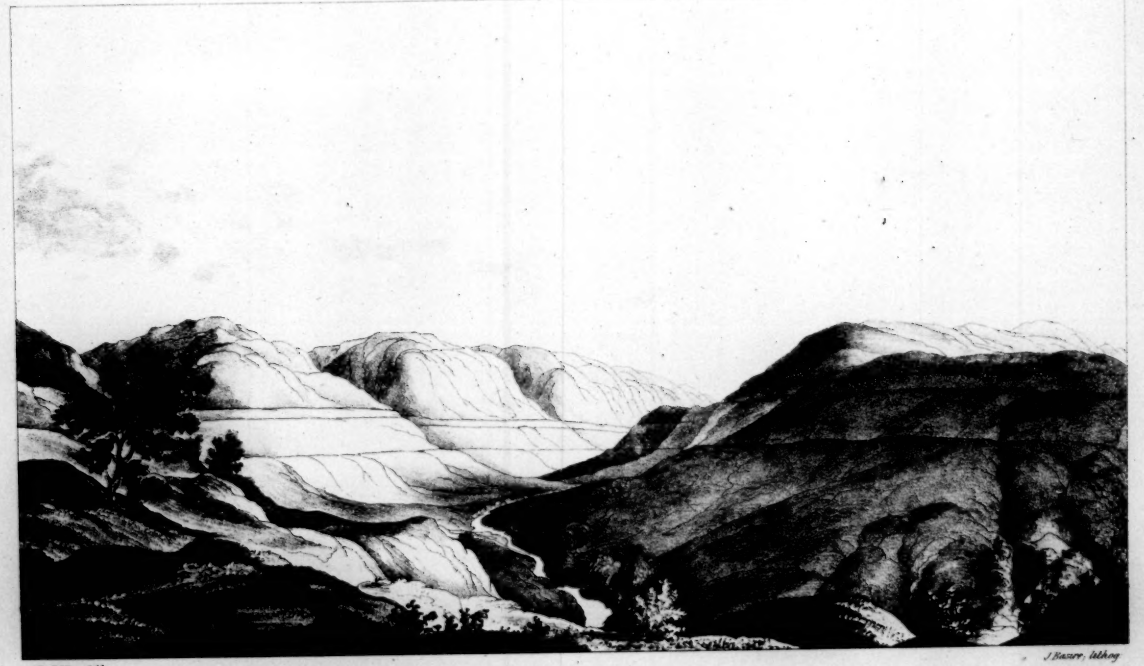
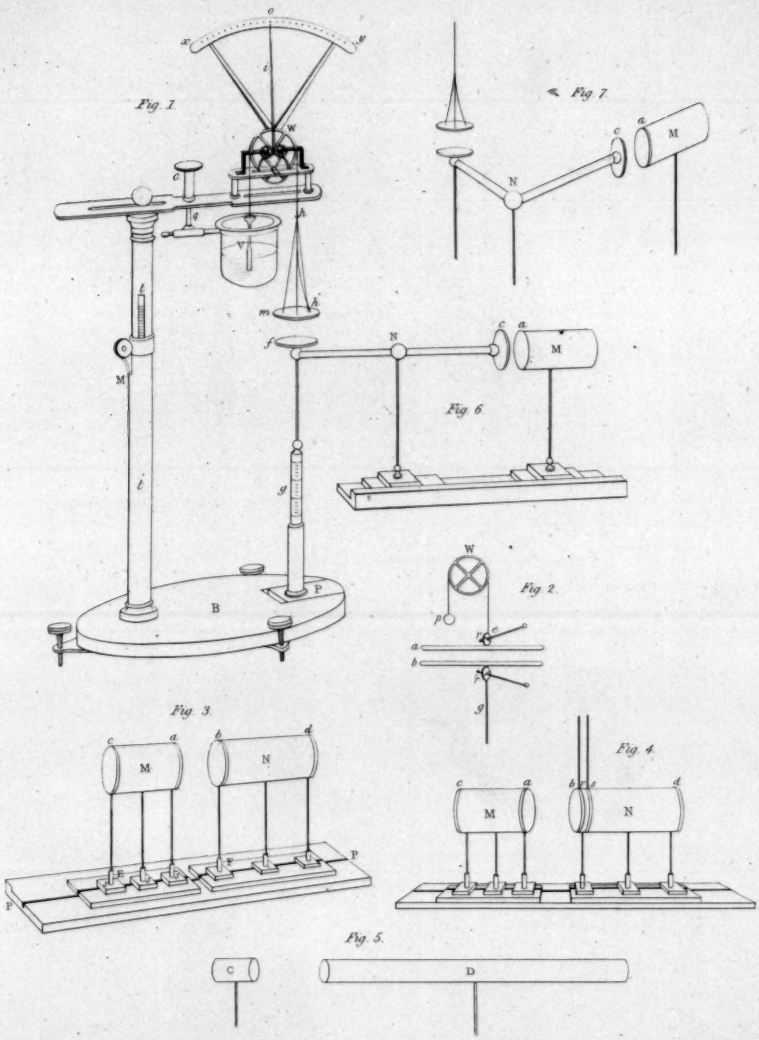


Parallel Roads or Shelves of Glen Roy and the adjoining Valleys.

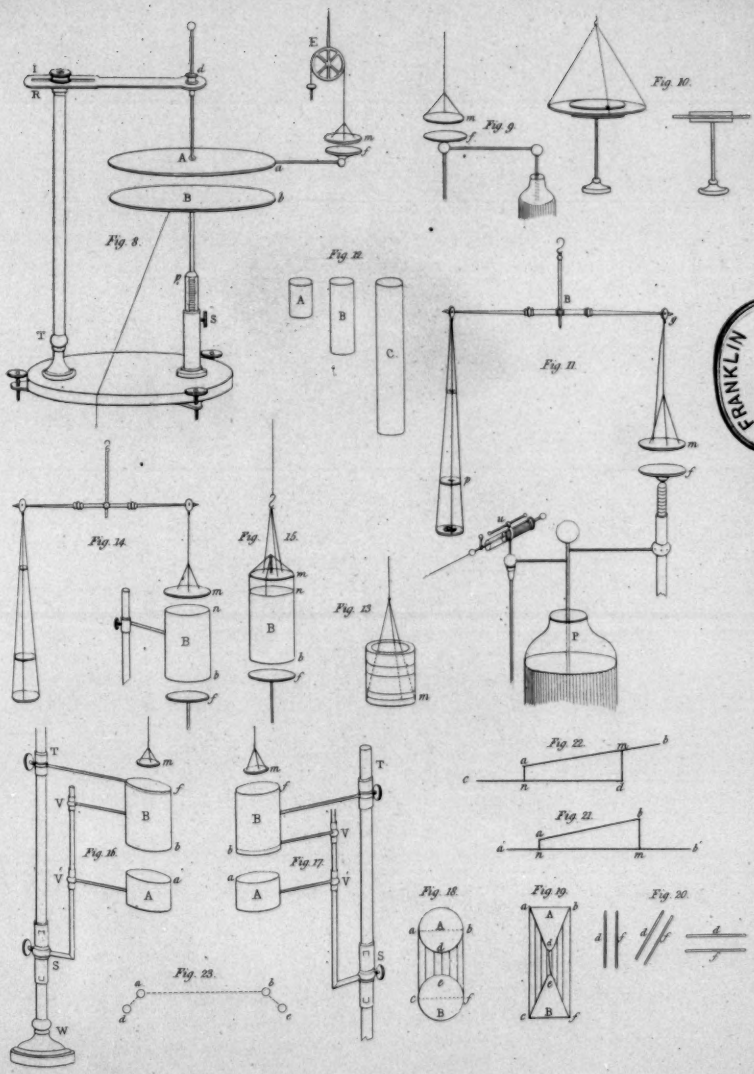


Albert Way, del.t J. Basire, lithog.

View of the Parallel Roads of Glen Roy.



J. Basire. sc.



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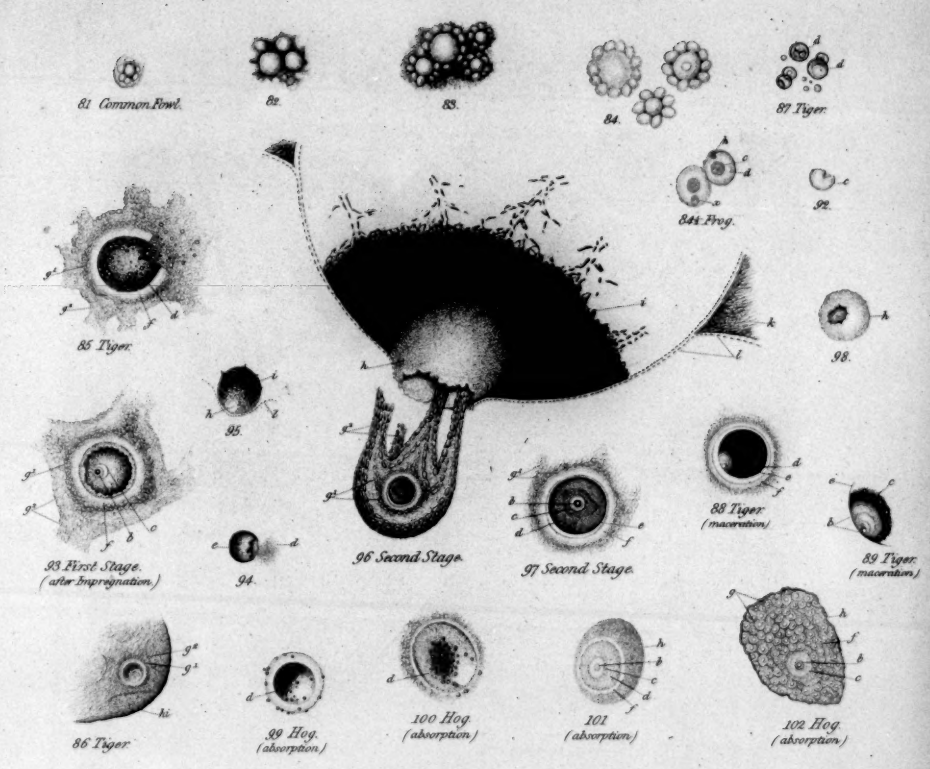
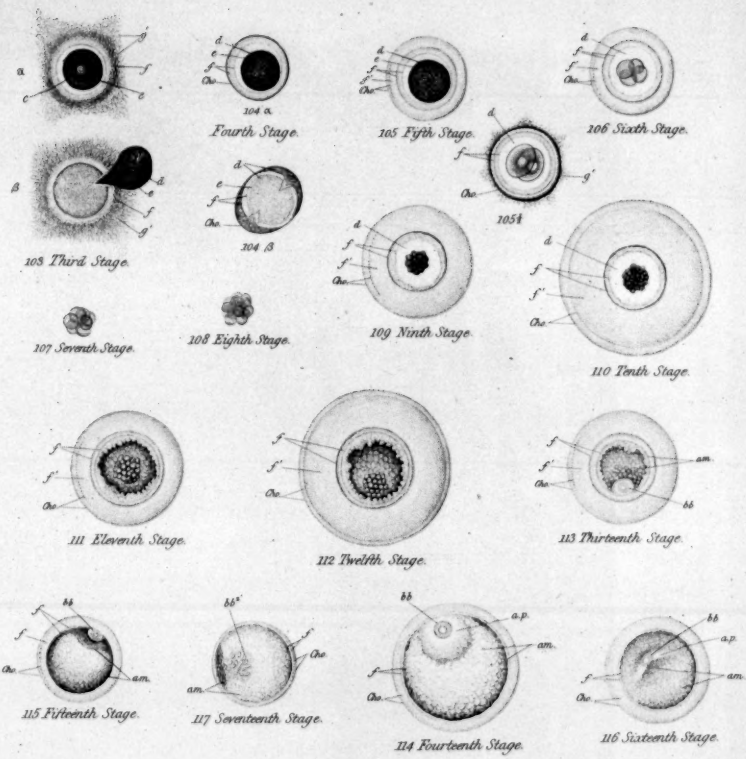
Embryology.



(Where the name of the animal is not given the Figure is from the Rabbit.)

b. Germinal Spot.
c. Germinal Vesicle
d. Yolk.—Yolk-globules (resides.)
e. Membrane originally investing the Yolk.—Yolk-ball
f. Thick transparent membrane of the ovarian Ovum. "Zona pellucida."
g. Peculiar Granules (resides) of the Ovisac
g^1 Tunica granulosa
g^2 Retinacula
h. Ovisac
i. Proper covering of the Ovisac.—Corpus luteum
hi. Graafian vesicle
k. Stroma
l. Peritoneum
x. Nucleus

Embryology.



Actual Sizes

103 104 106 109 110 111 112 113 115 117 114 116

(All the Figures represent Ova of the Rabbit:—in Fig.s 103 to 113 magnified 75 diameters; in Fig.s 114 to 117 50 diam.)

bb. The true Germ.
bb'. Future Vascular Lamina of the Umbilical Vesicle
c. Germinal Vesicle
d. Yolk
e. Membrane originally investing the Yolk
f. Thick transparent membrane of the ovarian Ovum—"Zona pellucida"
f'. Fluid imbibed by the Chorion
g'. Tunica granulosa
Cho. Chorion, subsequently villous
am. Amnion
a.p. Area pellucida

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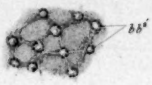
J.s Basire, sc.

Embryology.

118.
Eighteenth Stage.

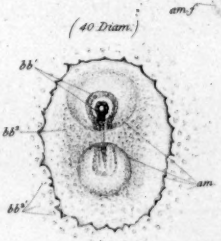
119.
Nineteenth Stage.



120.
Twentieth Stage.

121.
Twenty-first Stage.

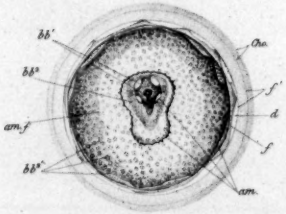
(40 Diam.)



122.

121 D.

(50 Diameters)



121 A ($\frac{5}{8}$''')

121 C.

(75 Diam.)

121 B.

(40 Diam.)

123.

(110 Diam.)

125.

126.

(40 Diam.)

124 (abnormal. $\frac{5}{8}$''')

(8 Diam.)

127.

Actual Sizes

(All the Figures are from Ova of the Rabbit.)

bb'. Central Portion of the Germ.
bb''. Peripheral Portion of the Germ.
bb'''. Lamina subsequently vascular.
d. Escaped Yolk.
f. Thick transparent membrane; "Zona pellucida."
f'. Fluid imbibed by the Chorion.
Cho. Chorion, subsequently villous.
am. Amnion.
am.f. Union of the membranes am. and f.

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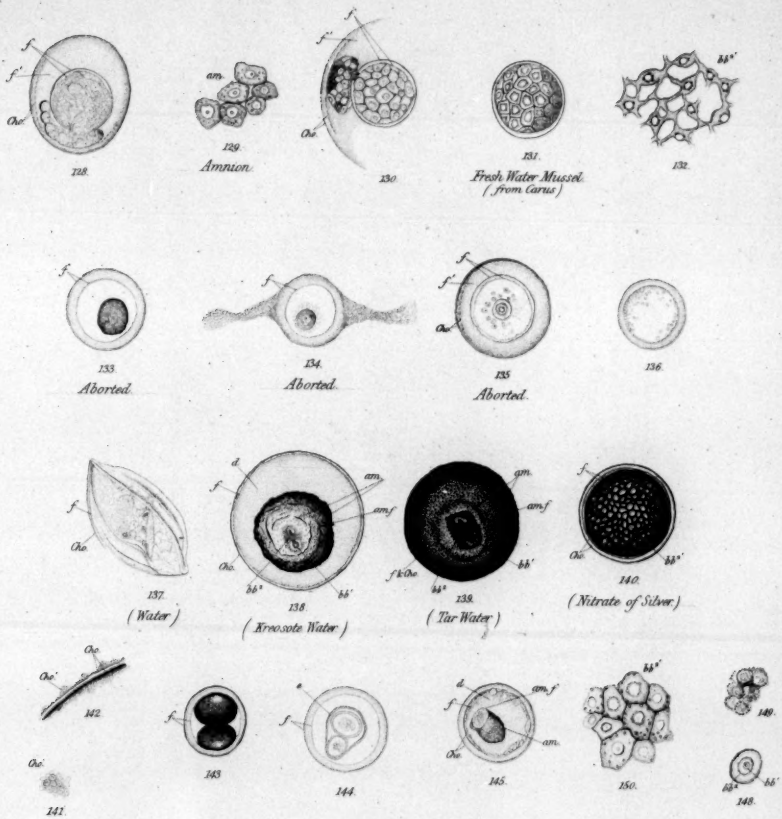
Embryology.



(All the Figures are from the Rabbit except Fig. 131.)

bb'. Central Portion of the Germ

bb². Peripheral Portion of the Germ

bb²'. Future vascular Lamina of the Umbilical Vesicle

d. Yelk_Escaped Yelk

f. Thick transparent membrane of the ovarian Ovum_"Zona pellucida"

f'. Fluid imbibed by the Chorion

Cho. Chorion subsequently villous_Villous Chorion

Cho.'. Villi

am. Amnion

am.f Union of the membranes am. and f.

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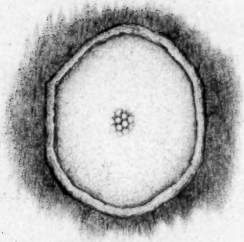
J. Basire, sc.

Embryology.

154.



151.

Vesicle; — the mulberry like object in the centre revolving on its own axis. (About 120 Diameters.)

155.

153.

An Ovum of 17 hours from the middle of the Fallopian Tube, showing the mode of origin of the Chorion (Cho.). This membrane is rising from the thick transparent membrane or "Zona pellucida" (f), surrounded by part of the Tunica granulosa (g'). (See also Pl. VI fig. 1054, representing an Ovum in which the Chorion (Cho) was on all sides equidistant from the membrane f.) (75 Diameters.)

152.

Vesicles from the surface of the mulberry like object in Fig. 151.

(The three Figures are from the Rabbit.)

c. Germinal Vesicle

e. Yolk-Ball

f. Thick transparent membrane of the ovarian Ovum. "Zona pellucida".

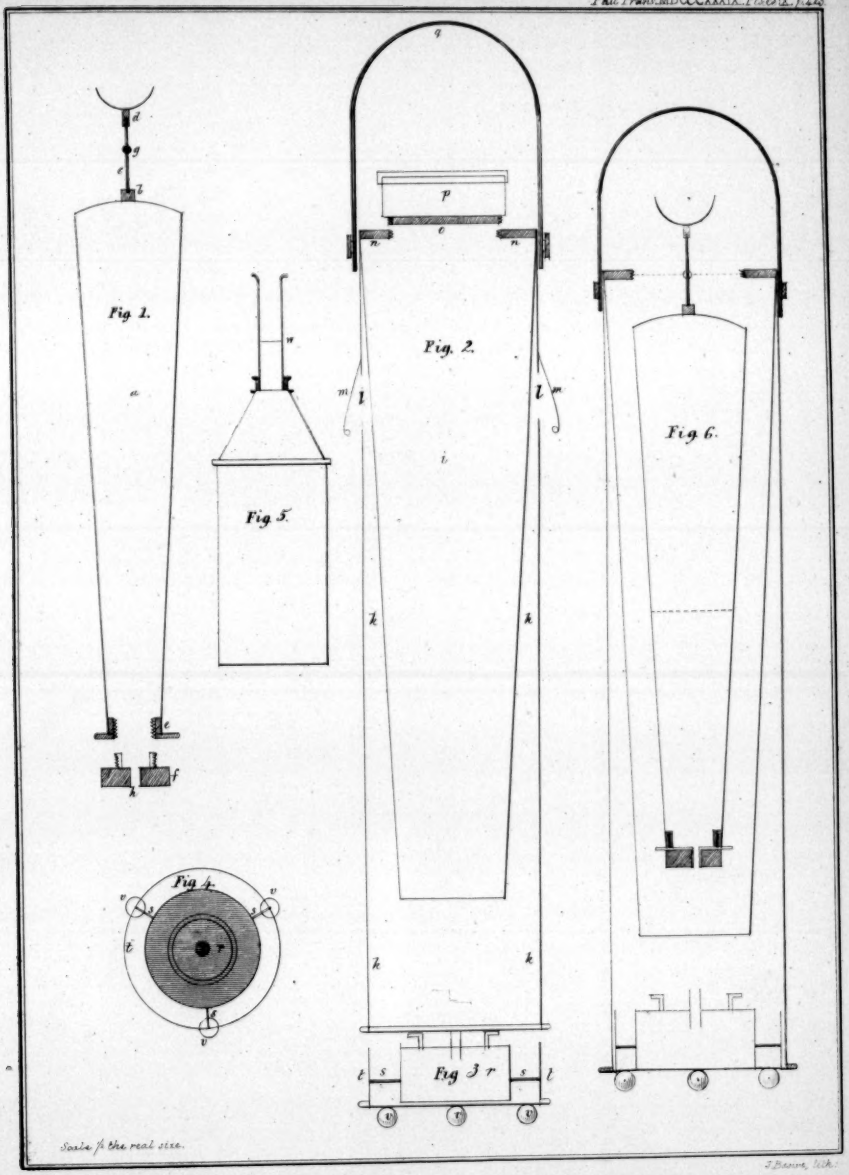
f'. Fluid imbibed by the Chorion

g'. Tunica granulosa

Cho. Chorion, subsequently villous.

Ad. Nat. del. Martin Barry.

I



J. Basire, lith.